The Incredible Complexity of Commercial Aviation

1. **All the amazing numbers and a bit of history**

2. Regulations and Agencies
FAA, CAB, NTSB, TSA, ATA, IATA, ICAO, EASA how they have advanced to keep us safe.
ETOPS. – Extended Twin Engine Range

3. Aircraft design and certification
Safety records, performance improvements, engines.
Basics of aerodynamics of flight, typical commercial flight.
Airliners near ready for Service

4. Aircraft manufacturing
Manufacturers, wood to composites, outsourcing, engines & introducing new airliners from Boeing, Airbus & the competition from China & Russia

5. Airline operations
History, scheduling, fees, labor, fuel, catering, sales , introducing new airplanes

6. Aircraft maintenance and Airports
FAA regulations, aircraft check levels, component repairs, problem feed back to FAA and manufacturers.
Major airports' traffic, ownership, fees, regulations, employment.

7.Air traffic control ,737 MAX issues and the effects of Covid19 on the commercial airline industry
FAA operations, purpose, system description the Next Gen system

8. Future of Commercial Aviation
What is next in commercial aviation, UDF, new fuels, Supersonic Transport, more advanced materials, or?

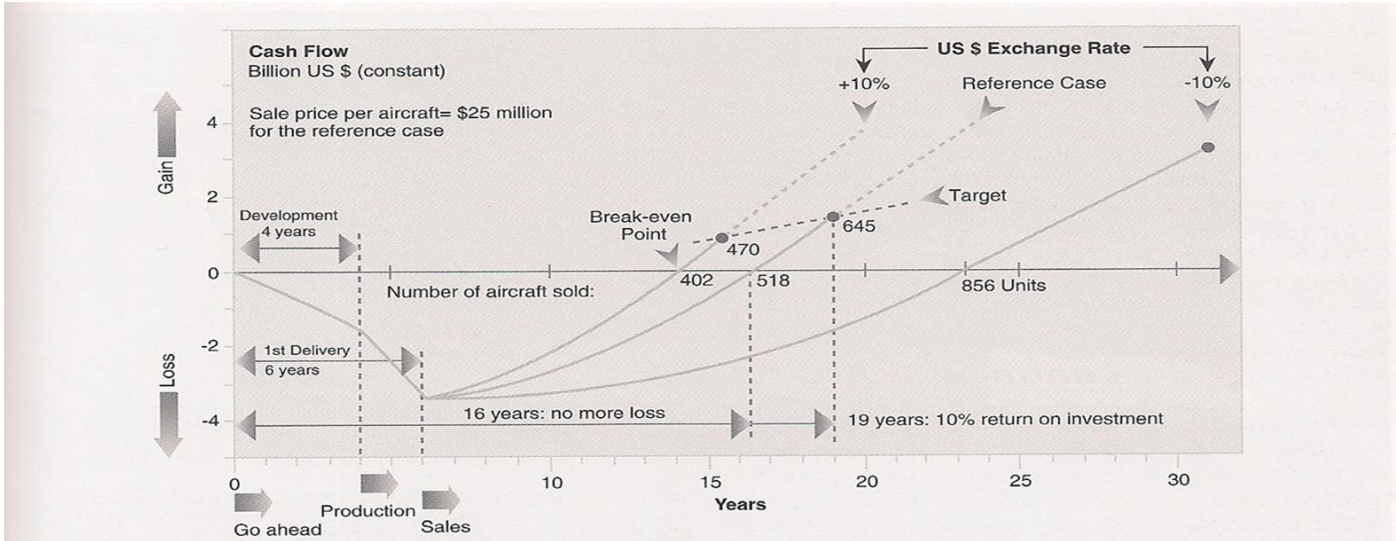
Session 4

Aircraft Manufacturing

Aircraft manufacturing: Introducing new airliners – how risky can it be? **VERY**

- The way the financials work for the airframe manufacturer and the other suppliers, namely the engine manufacturer is very different
- Airframe manufacturers profits are required upfront as aftermarket sales are very low compared to the engine manufacturers
- Engine manufacturers parts sales over the life of the

  engines provide most of the profits
- Aircraft manufacturers spend lots of money developing new or derivative aircraft for four to six years , if things go as planned , before any revenues come in
- As aircraft are delivered more spending to purchase materials, components, etc
- It can take many years for a new or derivative aircraft program to reach the break even point-if it ever does!
- Only after break even does the manufacturer earn a profit



Cash flow versus time. A very long period must elapse before any return on investment can be expected by a manufacturer, even under the most favourable conditions. This figure shows the rapid rate of loss in the early years of a new aircraft programme, followed by an even steeper decline when production starts. This is only arrested by the first sales, which may be no sooner than six years after programme launch. The slow recovery towards the break-even point is heavily dependent on monetary exchange rates, and for this hypothetical case break-even may be as early as 402 aircraft (after 14 years), or 856 aircraft (after 23 years). This highly risky business is obviously compounded not only when derivative models are introduced in a rapidly changing competitive world, but when a new aircraft is launched before the first has stopped losing money.

- The manufacturers' business case of a new or derivative aircraft is based on its projections of total aircraft sales
- If the projections are wrong it can be a financial disaster

Competition is at the *Highest Levels* with lots at stake – rough business

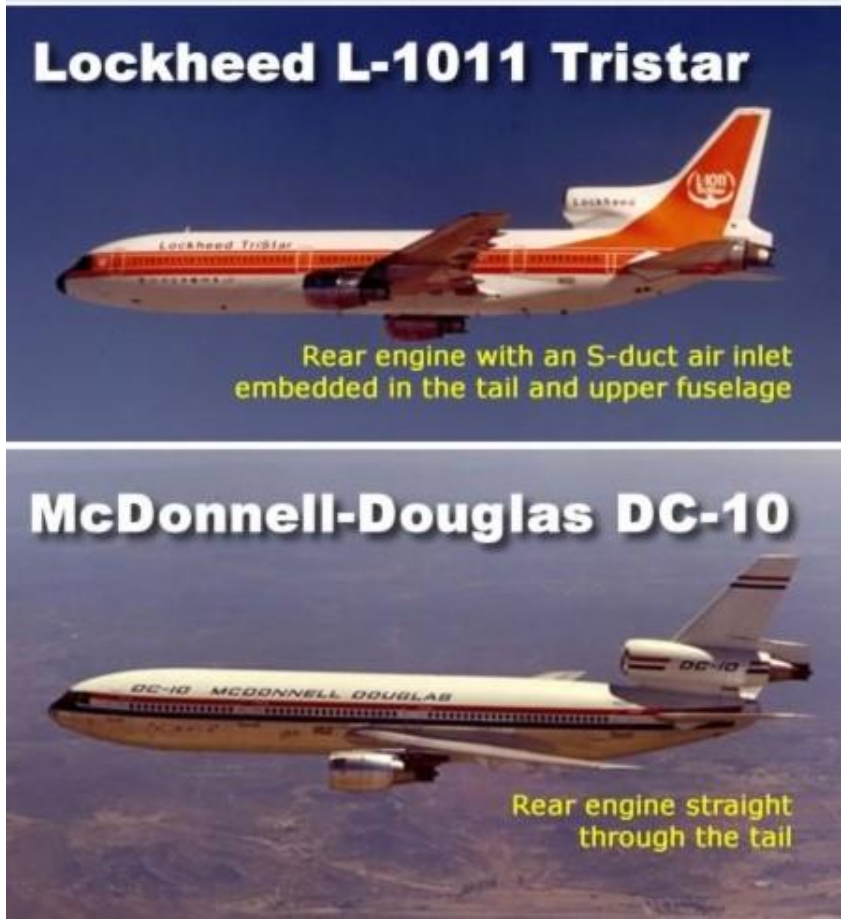
Aircraft manufacturing: Introducing new airliners – how risky can it be? **VERY**

- **Airbus** bet on a (4) engine, heavy loads (600 passengers), **A380**
- The development cost to introduce the **A380** was a **$14 Billion US Dollar's**
- The original sales projections were missed by 75%
- There is no way to offset the **A380's** development cost
- The true financial impact will never be known as the build-line will discontinue within the next year
- **AIRBUS** will be financially impacted for years to come

- **Boeing** with the recent **787** delays ,**737MAX** setback and issues on the **777X** introductions will experience financial implications as well for many years
- The **787** was 3 years late in its entry into
- The **737MAX** experienced the loss of 2 aircraft soon after introduction grounding future flight operations, earlier in 2019
- Late in Dec. 2019, the build line operation was halted on the **737Max**
- Its return to service continues to be extended by the **FAA**
- Boeing was hoping for 737MAX return to service in 2020
- Probably will be early 2021
- The **777X** aircraft introduction was also impacted with issues in several areas and delays continue
- These issues will affect **Boeing's** financials for years

Aircraft Manufacturing: - Introducing new airliners- An Example

- An example of a new design aircraft that was not a successful product for its manufacturer is the **Lockheed L1011 Tri Star** Wide body airliner
- In the 1960s, **American Airlines** approached **Lockheed** and competitor **Douglas** with the need for an airliner which could carry 250 passengers on transcontinental routes
- Both **Lockheed** and **Douglas** offered three engine wide body aircraft
- With similar capabilities-payload, range, etc
- The **Douglas DC-10** design was based on existing technology- based on its **DC-8** airliner
- **Douglas** selected the **GE CF6-6** high bypass engine which was based on the military **TF39** engine
- The **Lockheed L1011** design used new, more advanced technology
- **Lockheed** selected the **Rolls Royce RB-211-23** high bypass engine that was new design that used a composite fan blade



L1011 – Major negative impact on RR, Lockheed Martin & Eastern A/L's 8 minutes

https://www.youtube.com/watch?v=jkFYD7R_Xig

Aircraft Manufacturing: - Introducing new airliners

- **Eastern Airlines** worked closely with **Lockheed** who had selected the **Rolls Royce RB211** engine for the **L1011**
- **Rolls Royce's** problems with the **RB211** composite fan blade design and the limited sales of the **L1011** led to British government bailout of **Rolls Royce** and U.S. Government loan guarantees for **Lockheed**
- The lessons for the industry:
- Don't rely on technology that is not ready
  - Composite fan blades are now being used in several high bypass fan engines
- Make sure the market is large enough to support your new or derivative aircraft
  - **A380** will never break even

Composite Fan Blades CFAN 7:06

https://www.youtube.com/watch?v=eoNySabChvA

- The **A380** program will have a negative impact on **Airbus** for many years to come
- **Airbus** anticipated that the need for 1,200 aircraft
- Less than ~300 will be manufactured by its last year 2021
- The introduction of **ETOPS** and the development of Wide body twins has limited the need for the large **A380**
- Fifty plus years ago **Boeing** worked closely with a number of airlines led by **Pan AM (**and **Juan Trippe)** to develop the **747**
- **Boeing** chose to offer a derivative **747**, the **747-8** rather than a new very large aircraft to compete with the Airbus **A380**
- By end of **747** production in 2022 total will be ~1572 aircraft
  - Current variant is the 747-8
- Total success for the **Manufacturer** and the **Airlines**

Aircraft manufacturing: - Introducing new airliners – at what cost?

- Airlines continue to press the Manufacturers to produce more efficient airplanes
- Defined as lower fuel consumption, reduced maintenance costs and safety
- But at what price and risk can **Boeing** or **Airbus** consider new aircraft?
- The short-to medium-haul **A320** and the **Boeing 737** sell in higher volumes, but at a much lower price
- Yet with development costs of over $6 Billion, margins are lower
- The **Boeing 787** and **Airbus A350** serve a vital mid-sized segment where volume and value meet
- While the development costs for these aircraft are high, they are the workhorses for longer-haul route two engine ETOPS aircraft and will sell in large numbers through several Iterations and Variants

787

A350

Aircraft manufacturing: - Introducing new airliners – at what cost?

- Boeing's **737** started with the **PW JT8** Engine in the -100 and -200 series
- Then came the -300 with a different engine the **CFMI CFM56** and upgrades from the -300 to the -900 & NG models before the **737 MAX** was introduced last year
- **Airbus** did the same with its **A320** program
- The **A320NEO** (new engine option), a competitor for the **737MAX, uses a CFMI LEAP** engine or a **PW 1000G**
- This saves the manufactures in both introduction time and investment dollars
- In part, this is why **Boeing** has chosen to focus on the **737, 787** and **777**, and had fallen back on any upgraded 4 engine **747** as Airbus has also with the A320

737MAX

A320NEO

Some of the **737** outsourced components

- Fuselage, engine nacelles, thrust reversers and pylons - **Spirit AeroSystems (formerly Boeing), Wichita.**
- Slats and flaps - **Spirit AeroSystems (formerly Boeing), Tulsa.**
- Doors - **Vought, Stuart, FL**.
- Spoilers - **Goodrich, Charlotte, NC.**
- Vertical fin - **Xi'an Aircraft Industry, China**.
- Horizontal stabiliser - **Korea Aerospace Industries**.
- Ailerons - **Asian Composites Manufacturing, Malaysia.**
- Rudder - **Bombardier, Belfast** and **AVIC subsidiary Chengfei Commercial Aircraft (CCAC), China**

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- Tail section (aluminium extrusions for) - Alcoa / Shanghai Aircraft Manufacturing, China.
- Main landing gear doors - **Aerospace Industrial Development Corp, Taiwan.**
- Inboard Flap - **Mitsubishi, Japan.**
- Elevator - **Fuji, Japan.**
- Winglets - **Kawasaki, Japan**.
- Fwd entry door & Overwing exits - **Chengdu Aircraft, China.**
- Wing-to-body fairing panels and tail cone - **BHA Aero Composite Parts Co. Ltd, China.**

737 Assembly

- Factory employees must take **367,000 parts**; an equal number of bolts, rivets and other fasteners; and **36 miles of electrical wire**; and put them all together to form an airplane
- The fuselage is produced at a plant in Wichita, Kan.
- At that facility, employees attach the nose section of the airplane's fuselage to the center and tail sections
- When the fuselage is complete, it is strapped aboard a railroad car for a 2,175-mile train ride to Renton WA
- When the train arrives at the Renton factory, the fuselage is transferred to a large cart and wheeled to the final assembly building, where it spends about 13 days
- During the first stage of final assembly, factory workers focus on the interior
- They install insulation material along the inside walls of the fuselage, then add wiring and plumbing.

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- They install insulation material along the inside walls of the fuselage, then add wiring and plumbing.
- When the fuselage is ready to move to the next stage of production, an overhead crane located 89 feet above the floor lifts it high into the air and gently places it down into its next position
- Precision tools are used to install the landing gear and the two wings
- At this point, the **737** can roll along the factory floor and take its position in the moving production line
- **Boeing** became the first commercial airframe manufacturer to use the moving assembly line to build jetliners when first the **717**, and then the **737**, production lines were transformed into a moving line
- The moving line helps reduce the time to assemble the airplane and also cuts inventory and production costs
- The **737s** on the line move continuously at a **rate of 2 inches per minute**; the line stops only for employee breaks, critical production issues or between shifts
- Timelines painted on the floor help workers gauge the progress of manufacturing.

737 Assembly

- Near the beginning of the moving line, an overhead crane lifts the 23-foot-high tailfin into place so it can be attached
- Next, floor panels and serving galleys are installed and functional testing begins.
- In a test called the "**high blow**," mechanics pressurize the plane to trick it into thinking it is flying 92,847 feet in the air (more than twice as high as it will fly in service
- Inspectors make sure there are no air leaks
- In another test, large jacks lift the 154,983-pound airplane into the air so employees can test the landing gear retraction system
- As the airplane moves closer to the end of the line, the rest of the interior is completed - lavatories, luggage bins, ceiling panels, carpets, seats and other essentials are installed

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- As the airplane moves closer to the end of the line, the rest of the interior is completed - lavatories, luggage bins, ceiling panels, carpets, seats and other essentials are installed
- Right before the 737 exits the final assembly factory, mechanics attach the engines
- Once assembled, the airplane is towed to a hangar for painting
- About **50 gallons paint** are used on an average **737**; the paint weighs approximately **300 pounds**
- **737s** are painted per the airlines' specifications
- When painting is complete, the airplane is ready for a **Boeing test flight** - one last step to make sure the **737** is ready to fly passengers
- After Boeing test pilots fly the airplane, the customer's airline pilots take it for a test run
- When the customer test flight is complete, the **737** is ready for delivery to its new owner

737 Assembly

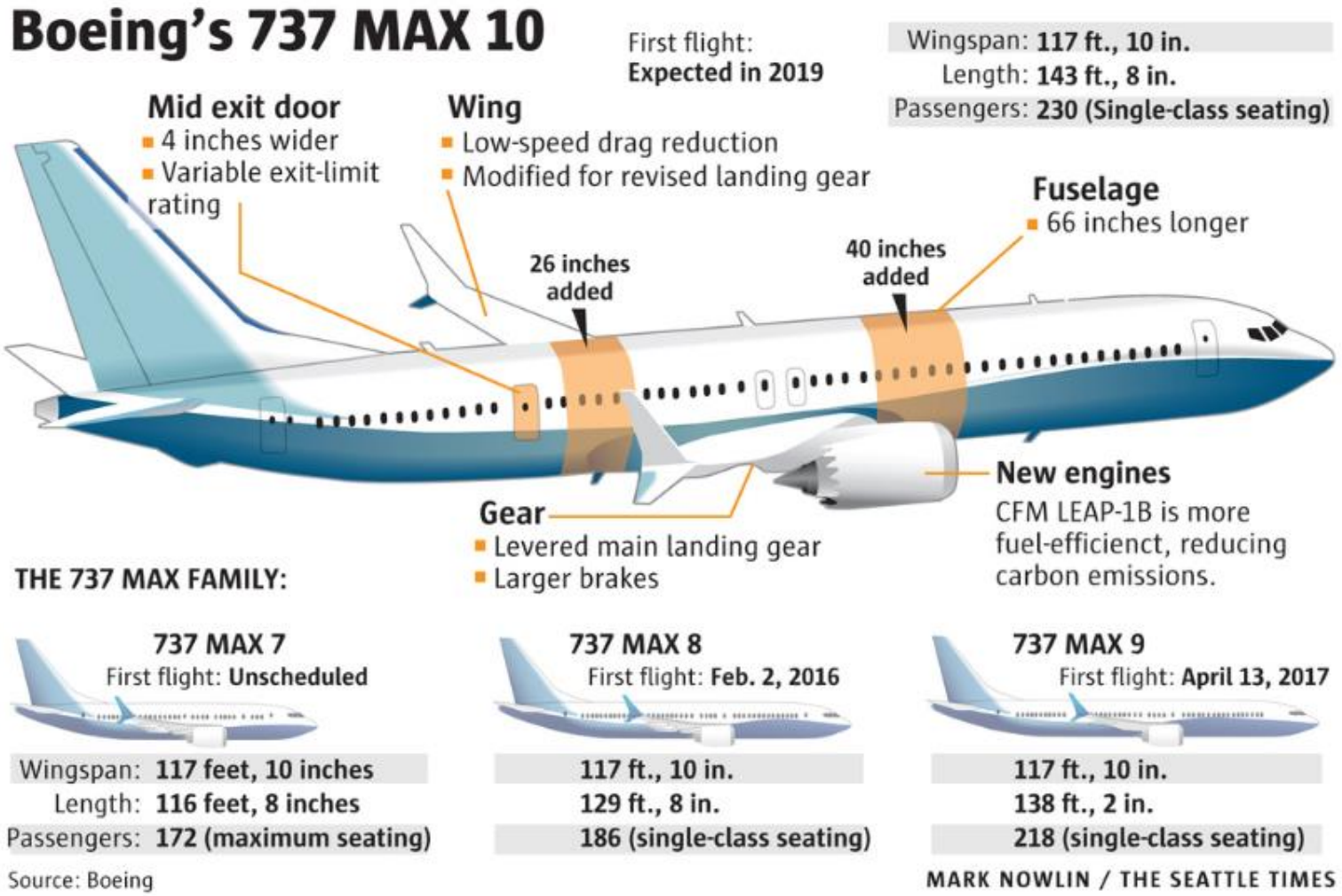
737 Assembly 2:16

https://youtu.be/Ssis6Csg3kA

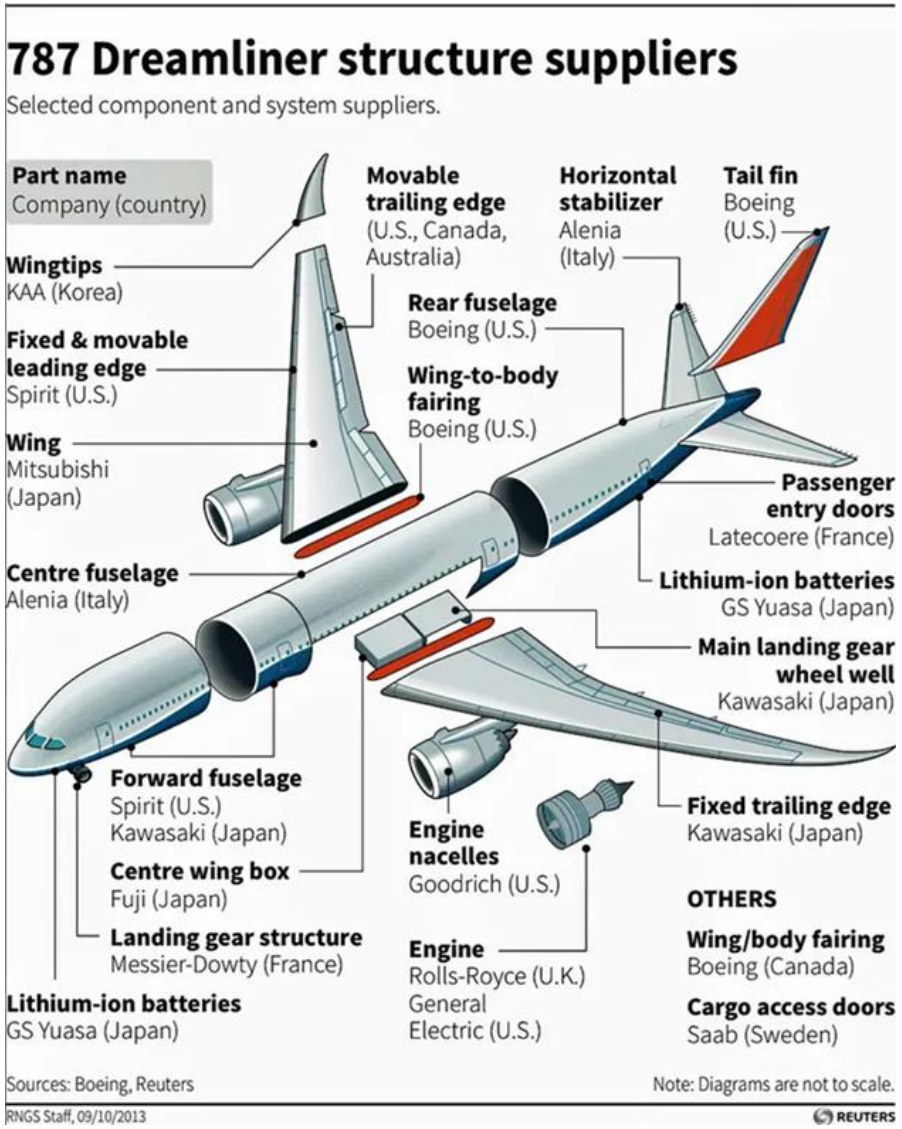
737 Assembly 6:20

https://youtu.be/LMCZh_alN7U

737 MAX Variants



787 Assembly

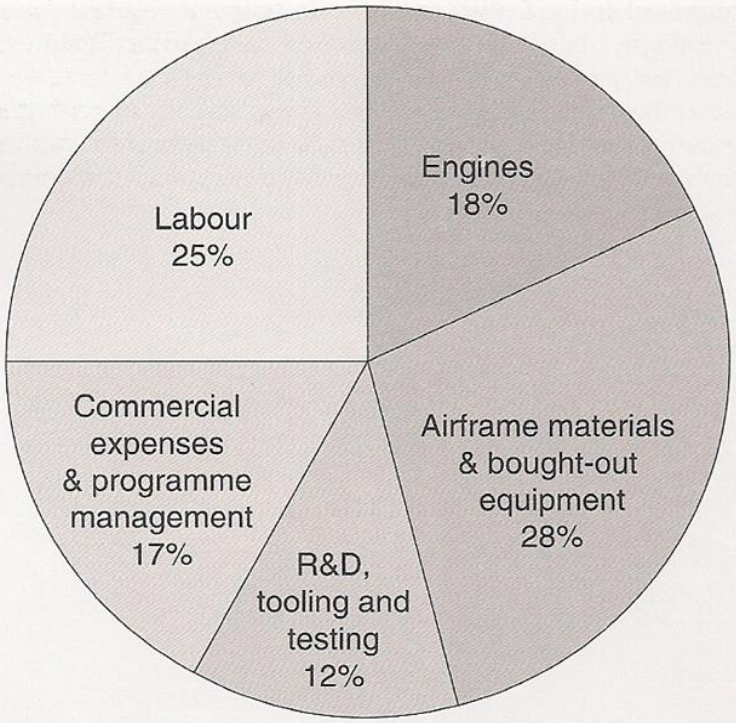


- Many aircraft major components are manufactured by various suppliers and brought to the final assembly location
  - By train for the **737** and aircraft for the **787**
  - By truck for some **Airbus** products
- This is a challenging scheduling and logistics problem
- The many components, up to six million for **747** size aircraft, are assembled at the manufacturers' final assembly sites
- Both **Airbus** and **Boeing** use international companies as suppliers

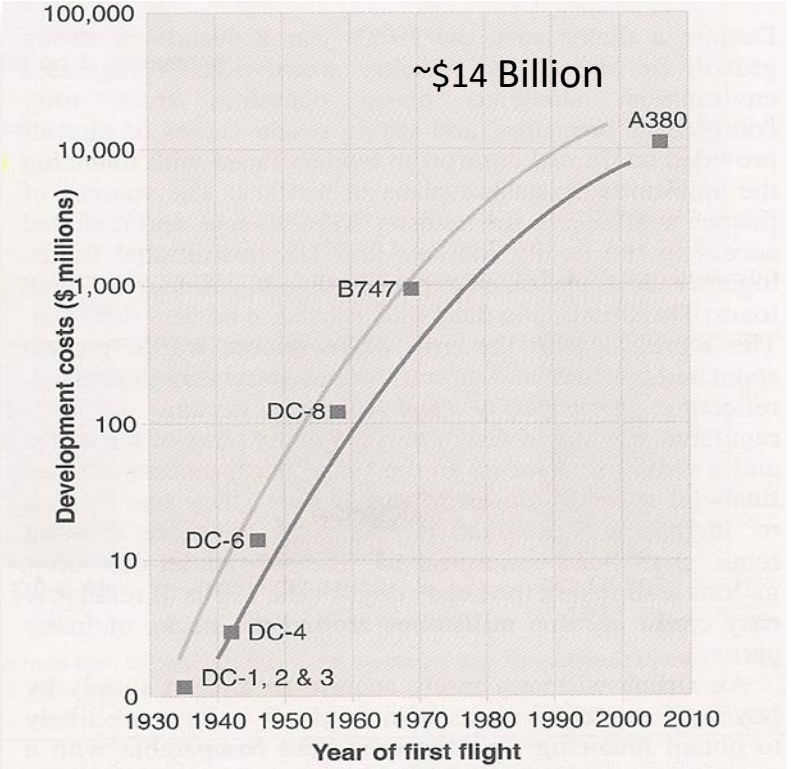
British Airways 787 Manufacture 3:59

https://www.bing.com/videos/search?q=787+manufacturing&&view=detail&mid=214EF6AF2E2219E5AE31214EF6AF2E2219E5AE31&&FORM=VRDGAR&ru=%2Fvideos%2Fsearch%3Fq%3D787%2Bmanufacturing%26FORM%3DHDRSC3

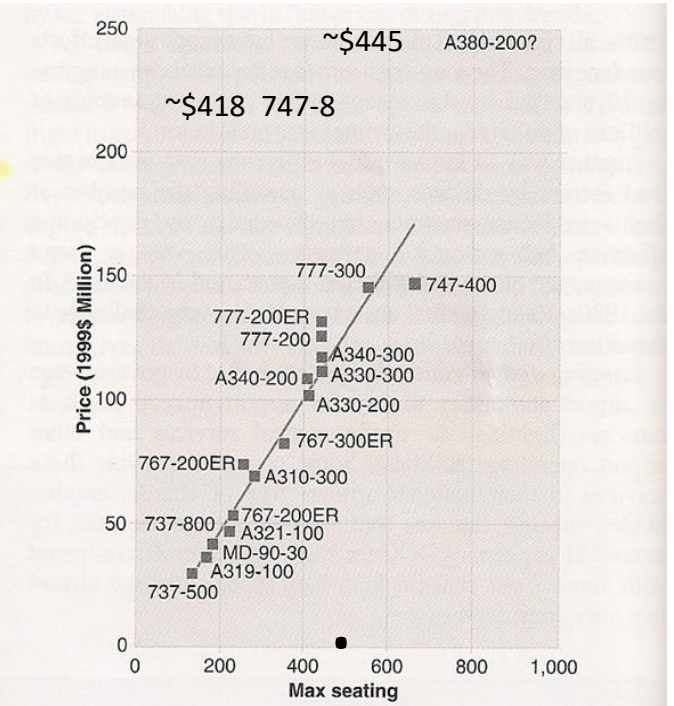
Aircraft manufacturing: Introducing new airliners



Breakdown of aircraft sale price for a new aircraft. This can only be approximate, but the chart is indicative of a medium-sized twin-engine aircraft. Proportions will vary according to how costs are allocated, and in particular the launch cost spread will be very much a function of the number of aircraft built. Even so, total aircraft production costs are likely to be of the order of 70 per cent of the aircraft selling price.
(Ray Whitford/*AIR International*)



Airliner development costs. Following the Second World War there was a dramatic rise in development costs that was only partly explained by greater weight and higher speed. It was British industry-wide experience through the 1950s that perceived that estimates of development cost allowing for these elements were too low by a factor of around three. Bristol Aircraft adopted a refinement by using a factor of 3.1416 (π). (Note the logarithmic vertical scale, and the fact that no attempt has been made to allow for inflation.)
(Ray Whitford/*AIR International*)



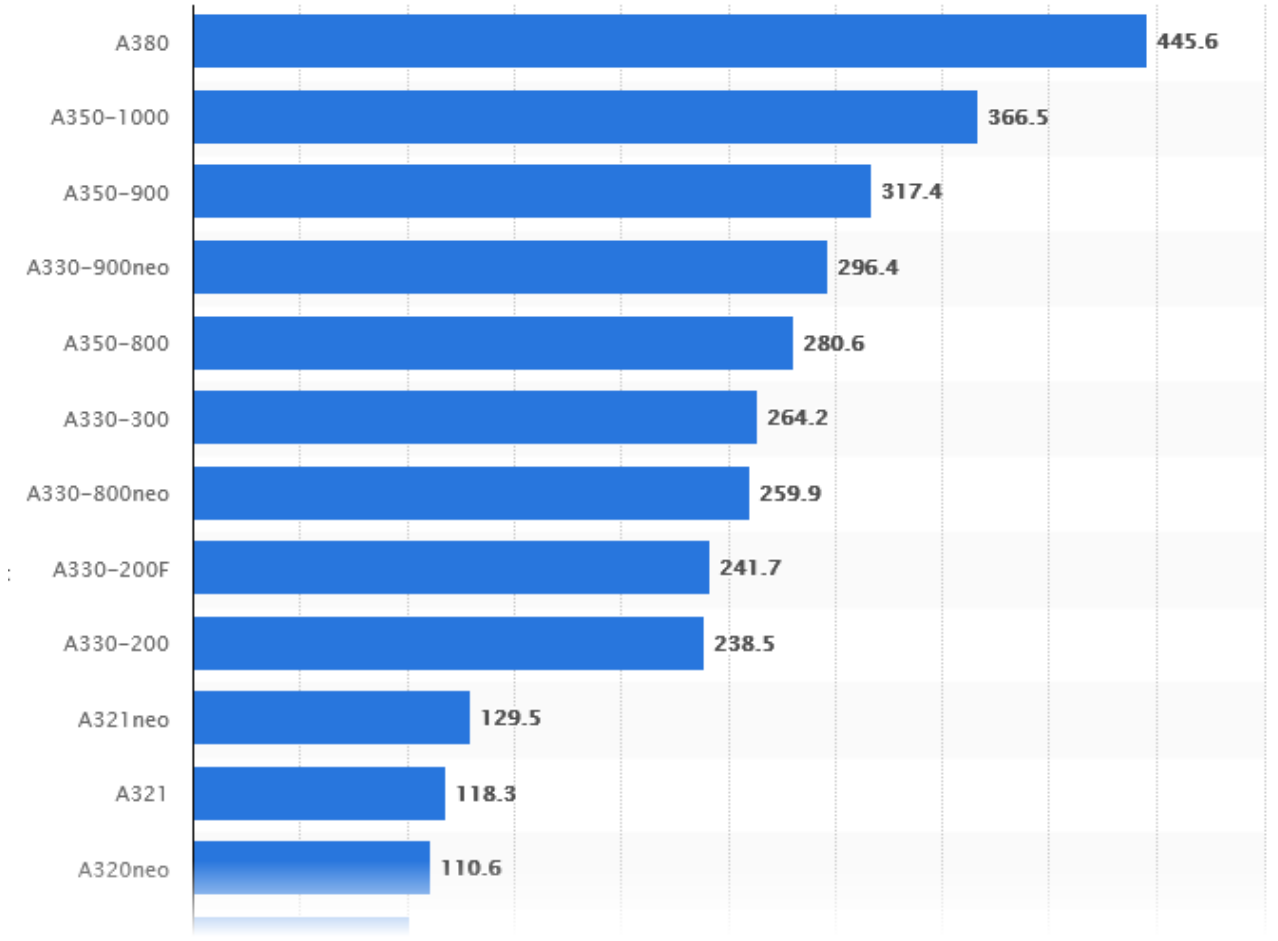
The growth in unit cost of airliners. This has in the main been justified economically in terms of airline operating cost (10¢/available seat-mile of the Ford Trimotor to 1¢/available seat-mile of the 747). It is noteworthy that the economic viability of the airliner has been maintained over the years by the constant increase in size, leading to so-called economies of scale. This in turn depended on ever-growing markets. The quoted price (source: Avmark) of current airliners is shown versus maximum seating (to give, for 1999, $270,000 per seat) with an extrapolation towards the 1,000-seat airliner. This produces a figure of $270 million, which is significantly higher than that suggested by press reports for the price of an A380-200.
(Avmark/Ray Whitford/*AIR International*)

The recovery time to break even is unacceptable for most business ventures

Aircraft Pricing-- Boeing

Airplane Families	$ in milli
737 Family	
737-700	89.1
737-800	106.1
737-900ER	112.6
737 MAX 7	99.7
737 MAX 8	121.6
737 MAX 200	124.8
737 MAX 9	128.9
737 MAX 10	134.9
747 Family	
747-8	418.4
747-8 Freighter	419.2
767 Family	
767-2C	-
767-300ER	217.9
767-300 Freighter	220.3
777 Family	
777-200ER	306.6
777-200LR	346.9
777-300ER	375.5
777 Freighter	352.3
777-8	410.2
777-9	442.2
787 Family	
787-8	248.3
787-9	292.5
787-10	338.4

Airbus



Aircraft manufacturing: - Introducing new airliners – Current Sources

*The **Boeing** Company – end of 2019*

Boeing Commercial Airplanes (BCA) is a division of the **Boeing** Company. It designs, assembles, markets, and sells jet **airliners** and business **jets.**

Boeing ...**Products**: 737, 747, 767, 777, 787 Current Available
Services: Maintenance, training
Number of employees: 72,465 (2017)
Total assets: US$92.333 billion (2017)

Boeing Commercial Airplanes, a business unit of The **Boeing** Company, is committed to being the leader in **commercial aviation** by offering **airplanes and services** that deliver superior design, efficiency and effectiveness.

The **Boeing** 707 is credited with launching the beginning the "**Jet** Age." It was decided that all model numbers that either began or **ended** in a "**7**" **would** be reserved for Boeing Commercial Airliners.

https://www.youtube.com/watch?v=BWwUTJM3jbA

747-8 Freighter 4 minutes

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747-8 Freighter 4 minutes

AIRBUS Group – end of 2019

Headquartered LEIDEN, Netherlands Employees 129,442

Airbus logged net orders in 2019 for 274 commercial aircraft from its A220, A320 and A350 XWB product lines in activity that included two new customers for the A220, additional market traction for the A320/A321 as reference products in the single-aisle segment, and further endorsements for the A350 XWB with repeat orders from two customers.
The single-aisle new business was led by the purchase finalization by Spirit Airlines of the U.S. for 100 A320neo Family aircraft, involving 47 A319neo, 33 A320neo and 20 A321neo versions and U.S.-based Air Lease Corporation's 102-aircraft order for 50 A220-300s, 25 A321neo versions and 27 A321XLRs (becoming a new customer for this extra long-range version).

https://www.youtube.com/watch?v=0WCc0bfZKS8

History of Airbus 2:27 minutes

https://www.youtube.com/watch?v=7hW95ws9JMQ

Which is better the 787 or the A350? 4:11 minutes

Aircraft manufacturing: Introducing new airliners

- The Boeing 777 has received more orders than any other wide-body airliner
  - As of August 2019, more than 60 customers had placed orders for 2,049 aircraft
  - With 1,609 delivered
- The most common and successful variant is the **777-300ER** with 810 delivered and 844 orders
- As of July 2018, **Emirates** was the largest operator with 163 aircraft
- By March 2018, the **777** had become the most-produced **Boeing** wide-body jet, surpassing the **Boeing 747**
- As of February 2019, the **777** has been involved in 28 aviation accidents and incidents since its introduction

https://www.youtube.com/watch?v=XEiWwRyq_9E

Noted above: - GE-9X for the 777 2:42 & 5.27 Minutes

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Noted above: - GE-9X for the 777 2:42 & 5.27 Minutes

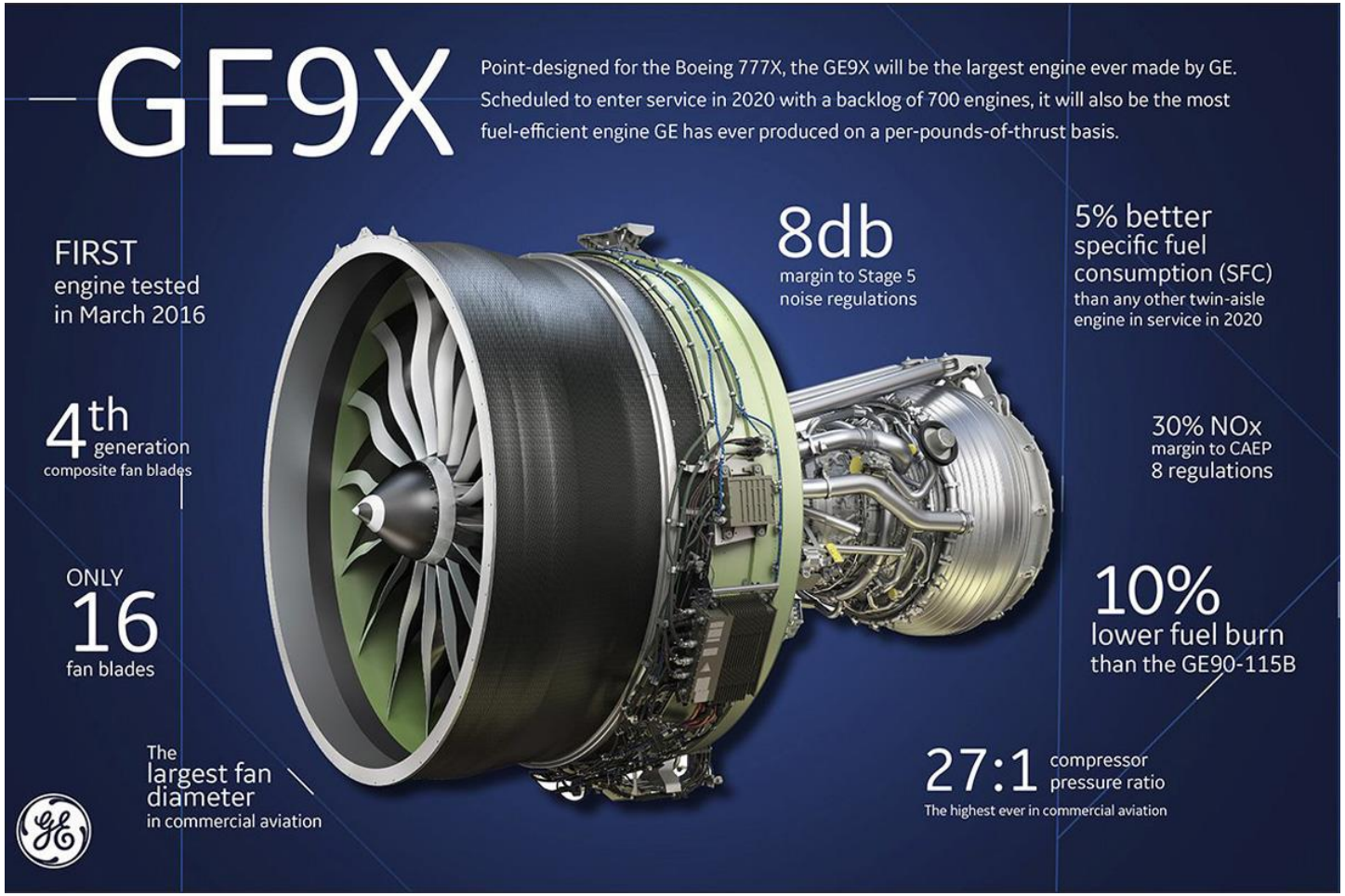
- Generally (exception is the 737) the Airlines will have an option as to which engine (GTE) they require
- Engine selection:
  - CFMI, (GEA & SAFRAN joint venture)
  - GE Aviation
  - Pratt & Whitney
  - Rolls Royce.
- Airframe manufacturer determines which engines will be offered on its aircraft
- The airline selects the engines and the Airframe Manufacturer matches that requirement to the airliner
- The engines are then sold to the Airframe Mfg.
- Multiple engine choices create better value for the airlines, price, warranty and guarantees
- Engine manufacturers prefer to be “sole source” on an aircraft

https://www.youtube.com/watch?v=eoNySabChvA

Composite Fan Blades CFAN 7:06 Minutes

Boeing 777X

Folding wing tips



GE9X	
Variant	**105B1A**
Type	**Dual rotor, axial flow, high bypass turbofan**
Combustor	**Single annular Twin Annulus Premixing Swirler**
Control	**dual channel FADEC**
Compressor	**1 fan, 3-stage LP, 11-stage HP**
Turbine	**2-stage HP, 6-stage LP**
Fan	**134 in (340 cm) diameter,[25] 16 wide chord composite blades**
Length	**224.0 in (5689.6 mm) [Fan Spinner to TRF aft most flange]**
Width × Height	**161.3 × 163.7 in (4097.0 × 4158.0 mm)**
Bypass ratio	**9.9:1**
Overall pressure ratio	**60:1, HPC pressure ratio: 27:1**
Weight	**21,230 lb (9,630 kg)**
Takeoff thrust	**110,000 lbf (490 kN)**
Thrust/weight	**5.2**
RPM, 100%	**LP 2355, HP 9561**

Next Session
Airline Operations