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.

- 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
- 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**

[Composite Fan Blades CFAN 7:06](https://www.youtube.com/watch?v=eoNySabChvA)
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
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
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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- 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_aIN7U
737 MAX Variants

Boeing’s 737 MAX 10

Mid exit door
- 4 inches wider
- Variable exit-limit rating

Wing
- Low-speed drag reduction
- Modified for revised landing gear

Fuselage
- 66 inches longer

New engines
CFM LEAP-1B is more fuel-efficient, reducing carbon emissions.

THE 737 MAX FAMILY:

737 MAX 7
First flight: Unscheduled
- Wingspan: 117 feet, 10 inches
- Length: 116 feet, 8 inches
- Passengers: 172 (maximum seating)

Source: Boeing

737 MAX 8
First flight: Feb. 2, 2016
- 117 ft., 10 in.
- 129 ft., 8 in.
- 186 (single-class seating)

737 MAX 9
First flight: April 13, 2017
- 117 ft., 10 in.
- 138 ft., 2 in.
- 218 (single-class seating)
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

Aircraft manufacturing: Introducing new airliners

The recovery time to break even is unacceptable for most business ventures
Aircraft Pricing -- Boeing

<table>
<thead>
<tr>
<th>Airplane Families</th>
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<tbody>
<tr>
<td>737 Family</td>
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<td>737-700</td>
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<td>767-300ER</td>
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<td>767-300 Freighter</td>
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Airbus

<table>
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<th>Model</th>
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<td>A380</td>
<td>445.6</td>
</tr>
<tr>
<td>A350-1000</td>
<td>366.5</td>
</tr>
<tr>
<td>A350-900</td>
<td>317.4</td>
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<tr>
<td>A330-900neo</td>
<td>296.4</td>
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<tr>
<td>A350-800</td>
<td>280.6</td>
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<tr>
<td>A330-300</td>
<td>264.2</td>
</tr>
<tr>
<td>A330-800neo</td>
<td>259.9</td>
</tr>
<tr>
<td>A330-200F</td>
<td>241.7</td>
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<tr>
<td>A330-200</td>
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<tr>
<td>A321neo</td>
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<td>A321</td>
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</tr>
<tr>
<td>A320neo</td>
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</table>
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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https://www.youtube.com/watch?v=JzZJ7zXtF6E

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

https://www.youtube.com/watch?v=8xq9c0bZjzg

787-9 Dreamliner  3 minutes

https://www.youtube.com/watch?v=3nYlstP7wlg

Aircraft manufacturing: - Introducing new airliners – Current Sources
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=XEiWwRyg_9E

Noted above: - GE-9X for the 777 2:42 & 5.27 Minutes
Aircraft manufacturing: Introducing new airliners

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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=XEiWwRyq_9E

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

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

Composite Fan Blades CFAN  7:06 Minutes
Boeing 777X

Folding wing tips
Point-designed for the Boeing 777X, the GE9X will be the largest engine ever made by GE. Scheduled to enter service in 2020 with a backlog of 700 engines, it will also be the most fuel-efficient engine GE has ever produced on a per-pounds-of-thrust basis.

### GE9X Specifications

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