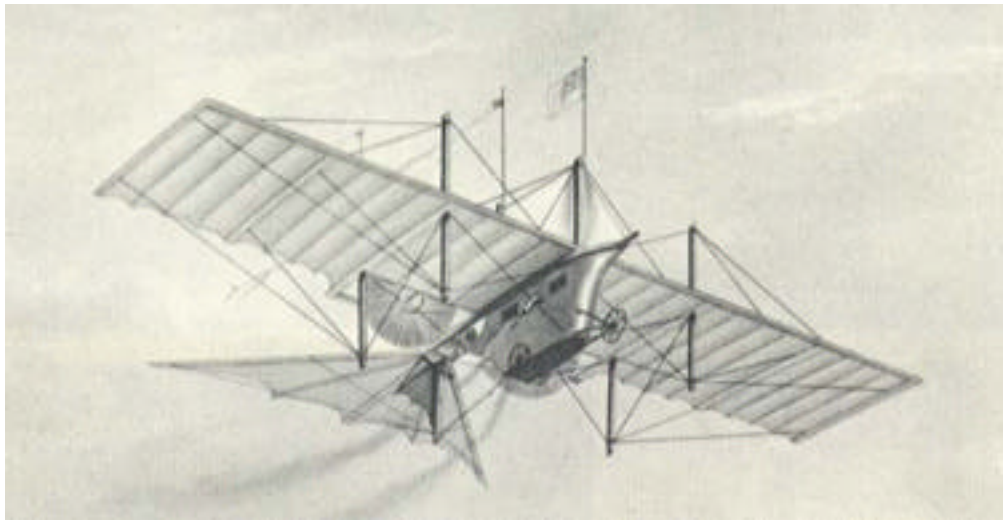
Evolution of Commercial Transport Aircraft Since 1926

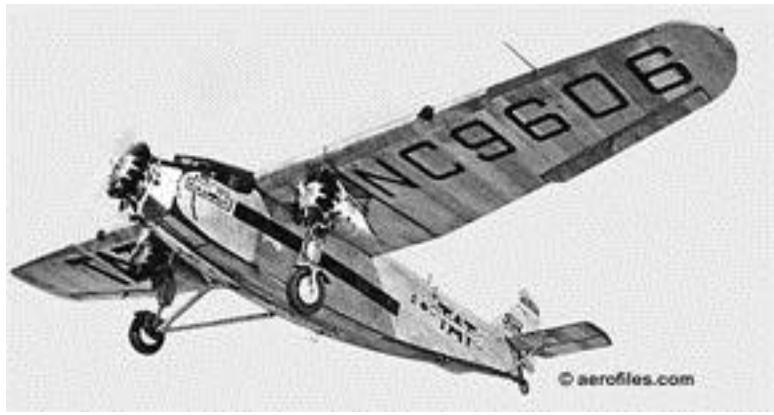
Robert Stengel, Princeton University, 2003

- *Henson's* and *Stringfellow's* plan for steam powered aircraft and international *Aerial Transit Company* (1846)
- Air Commerce Act of 1926 encouraged formation of new airlines
  - **Northwest (1926)**
  - **Eastern (1927)**
  - **Pan Am (1927)**
  - **Boeing Air Transport (1927)**, became **United (1931)**
  - **Delta (1928)**
  - **American (1930)**
  - **TWA (1930)**
- *Ford 3-AT Tri-Motor* (1926) preceded more successful later versions (note open cockpit)



Ford Tri-Motor Aircraft ("Tin Goose")

- All-metal aircraft
- 12 passengers, 110 mph
- Stewardesses were trained nurses
- *4-AT* (1926) and *5-AT* (1929) at right
- Flown by United Airlines
- *14-AT* (below) was the last of the line (never flew)



Commercial Aircraft of the 1930s

- Streamlining, engine cowlings
- *Douglas DC-1, DC-2, DC-3*

- *Lockheed Express, Boeing 247,* exterior and interior

The DC-2-1/2

- Aircraft were rugged and simple
- *DC-3* with *DC-2* right wing
- Quick fix to fly aircraft out of harm's way during WWII

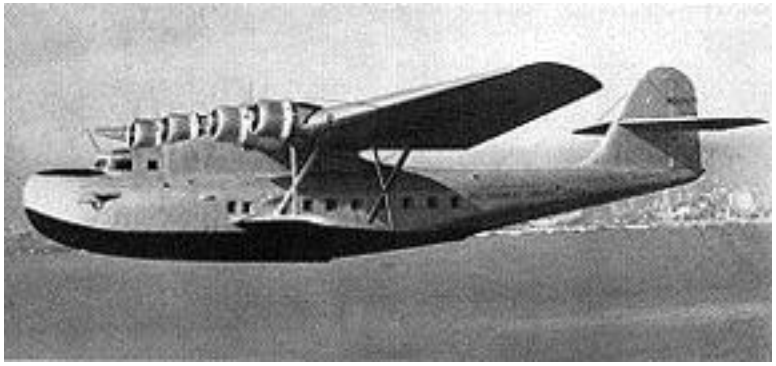
Comfort and Elegance by the End of the Decade

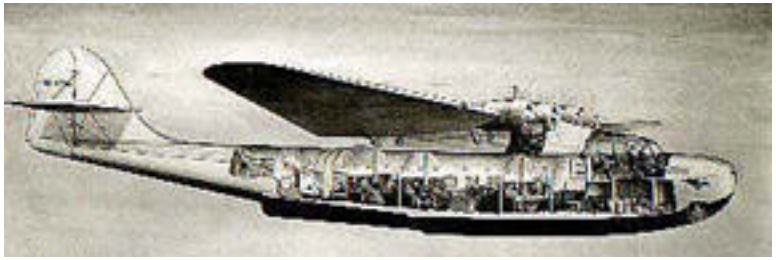
- *Boeing 307*, 1st pressurized cabin (1936), flight engineer, *B-17* pre-cursor, large dorsal fin (exterior and interior)

- Sleeping bunks on transcontinental planes (e.g., *DC-3*)
- Full-size dining rooms on flying boats

Flying Boats (Seaplanes) Opened New Markets for Commercial Air Travel (1926-1935)

- *Dornier Do.X, Sikorsky S-40, Martin M-130*, Pan Am “Clipper” base at Miami
- No need for runways





Seaplanes Became the First TransOceanic Air Transports (1934-1952)

- PanAm led the way
  - 1st scheduled TransPacific flights(1935)
  - 1st scheduled TransAtlantic flights(1938)
- 1st scheduled non-stop Trans-Atlantic flights (*VS-44*, 1939)
- *Boeing B-314, Vought-Sikorsky VS-44, Shorts S-23, Shorts Solent, Saunders Roe Princess*
- Superseded by more efficient landplanes

Commercial Aircraft of the 1940s

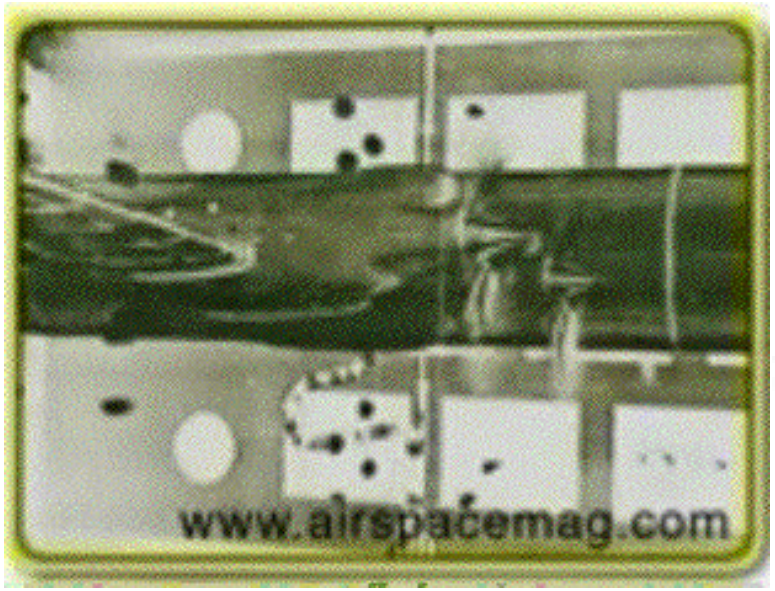
- Pre-WWII designs
- Derivatives of military transport and bomber aircraft of WWII
- *Douglas DC-4, Vickers Viking, Convair 240, Boeing Stratoliner 377* (from *B-29*), *Lockheed Constellation 749* (from *C-69*)

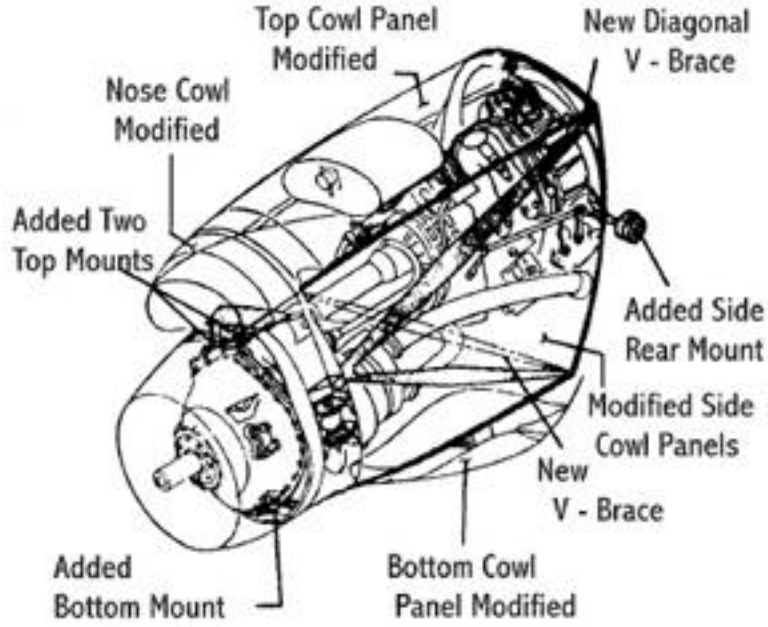
Commercial Propeller-Driven Aircraft of the 1950s

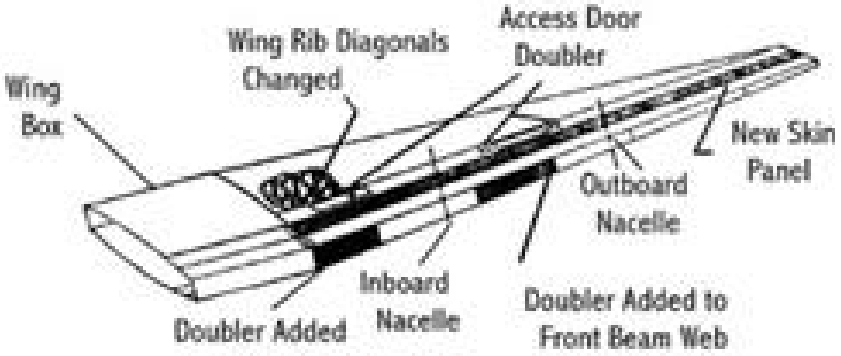
- Introduction of the turboprop engine
- *Douglas DC-6, DC-7, Lockheed Starliner 1649, Vickers Viscount, Bristol Britannia, Lockheed Electra 188*

Aeroelastic Problems of the Lockheed Electra

- Prop-whirl flutter, 2 fatal accidents (1959-60)
- Structural modifications made; aircraft remained in service until 1992
- Predecessor of *US Navy Orion P-3*, still in service





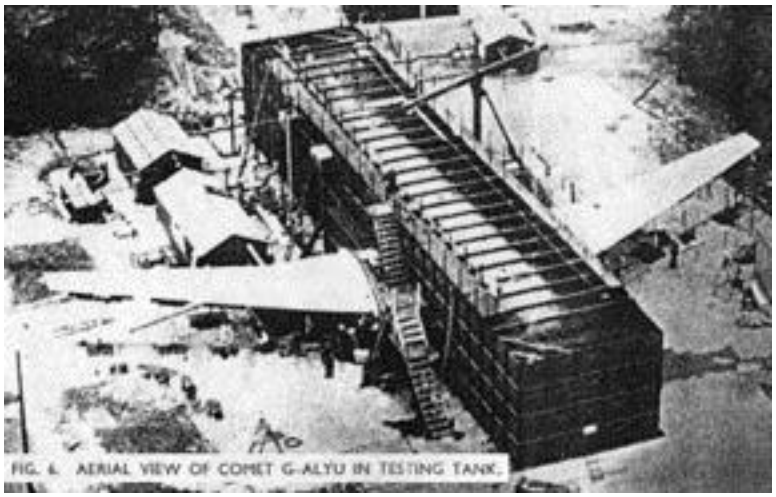


Commercial Jet Aircraft of the 1950s

- Low-bypass ratio turbojet engines
- *deHavilland Comet* (1954)
  - 1st commercial jet transport
  - engines buried in wings
- *Boeing 707* (1957)
  - derived from *USAF KC-135*
  - engines on pylons below wings
  - largest aircraft of its time
- *Sud-Aviation Caravelle* (1959)
  - 1st aircraft with twin aft-mounted engines

Fatigue Failure of the deHavilland Comet

- 3 in-flight breakups in first 2 years of commercial use
- Extensive structural test program revealed the cause
- Repeated pressurization and de-pressurization caused fatigue failure at stress concentration points
- Predecessor to the *RAF Nimrod* (still flying)



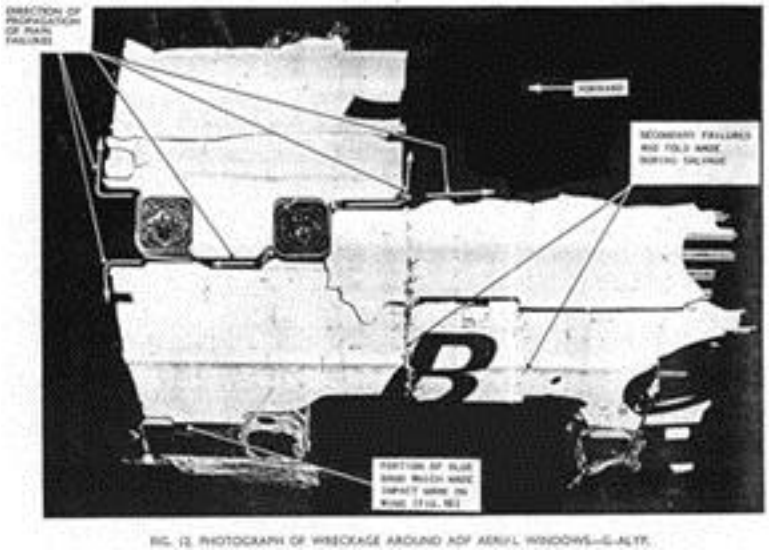


FIG. 12. PHOTOGRAPH OF WRECKAGE AROUND ADF AERIAL WINDOWS—G-ALYP.

Small Commercial Jet Aircraft of the 1960s

- Preponderance of aft-mounted 2- and 3-engine configurations (*BAC 1-11, Douglas DC-9*)
- *Boeing 727* (1963)
  - 1st aircraft with three aft-mounted engines
- *Hawker-Siddeley Trident* (1964)
- *Boeing 737* (1967)

Large Commercial Jet Aircraft of the 1960s

- Preponderance of pylon-mounted 4-engine configurations (*Convair 880, DC-8, Stretched DC-8, Boeing 747*)
- *DC-8* design was well-suited to a stretch (fuselage plugs fore and aft of wing; *B-707* was not

Aeroelasticity of Large Aircraft

Atypical Jet Transport Configurations

- Four aft engines (Vickers VC-10)
- Pylon-mounted engines above wing (VFW 614)

- Forward swept wing (Hansa 320B)
- High-wing, 4-engine, small configuration (BAE 146)

Commercial Jet Aircraft of the 1970s

- Introduction of the 2/3-engine jumbo jets (*Lockheed L-1011, McDonnell-Douglas DC-10, Airbus A-300*)
- Supersonic transports
  - *BAC/SA Concorde* (1972)
  - Tupolev Tu-144 (1977)

Commercial Jet Aircraft of the 1980s

- Extensions of the 1970s transports (*Boeing 757, 767, Airbus A-310, A-320*)
- Introduction of fly-by-wire control (*A-320*)
- Cockpit commonality

Commercial Jet Aircraft of the 1990s

- Derivatives of 1980s designs (*McDonnell-Douglas MD-11, Boeing 747-400, Airbus A-330*)
- First Boeing fly-by-wire design (*B-777*, with *B-247*)
- First 4-engine Airbus (*A-340*)

Commercial Jet Aircraft of the 2000s

- Derivatives of 1990s designs (stretch and shrink)
- Improved engines
- Lighter structures
- *Boeing 737-600, -700, -800, -900, B-717 (from DC-9, MD-80), B-777-300*
- First **Very Large Aircraft** (*Airbus A-380*) in development

Conceptual Trans/Supersonic and Joined-Wing Aircraft

Blended Wing-Body (BWB) Jet Transports

Source: *Flight To The Future*, Joe Mizrahi
http://members.home.net/rebid/bldwing.htm

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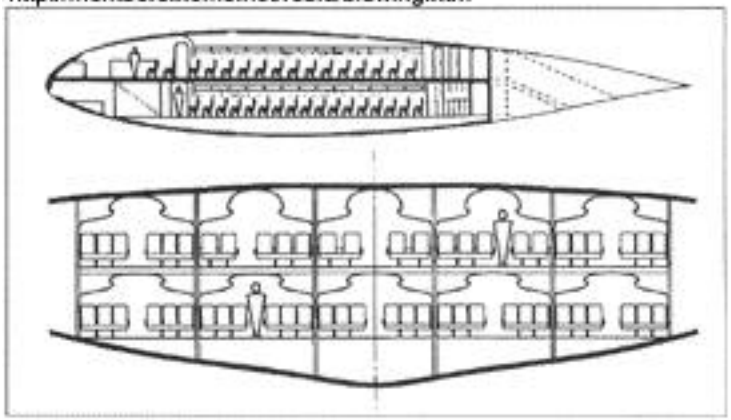


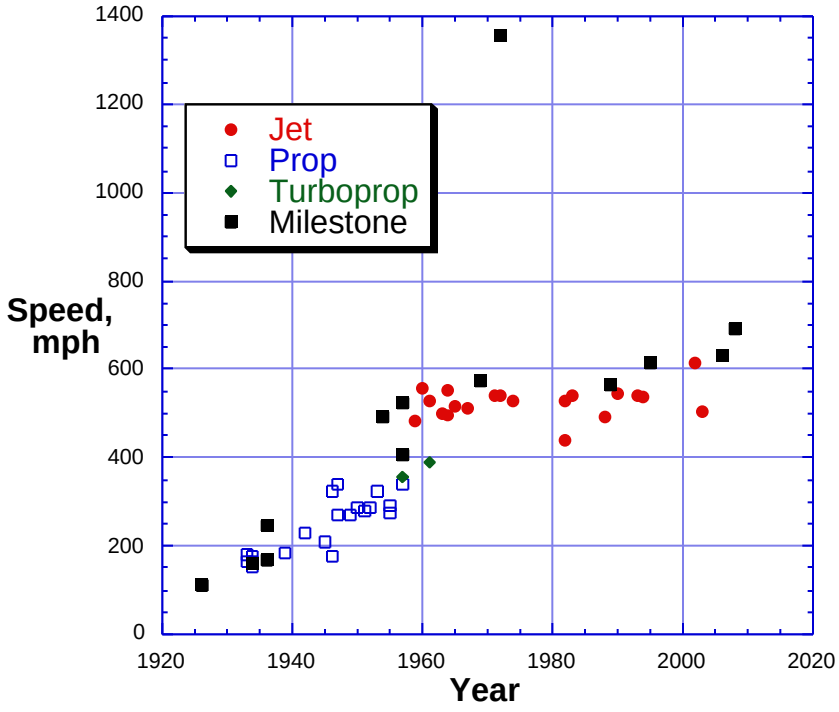
Large Aircraft Flying Qualities

- High wing loading, effects on dynamics
- Distance from pilot to center of mass
- Slosh susceptibility of large tanks
- High wing span -> short relative tail length
  - Higher trim drag
  - Increased **yaw due to roll**, need for rudder coordination
  - **Reduced rudder effect**
- Altitude response during landing approach
  - Increased non-minimum-phase delay in response to elevator
  - Potential improvement from canard
- Longitudinal dynamics
  - **Phugoid/short-period resonance**
- Satisfactory rolling response (e.g., time to bank)
- Reduced static stability of cruise-efficient designs
- Off-axis passenger comfort in BWB turns

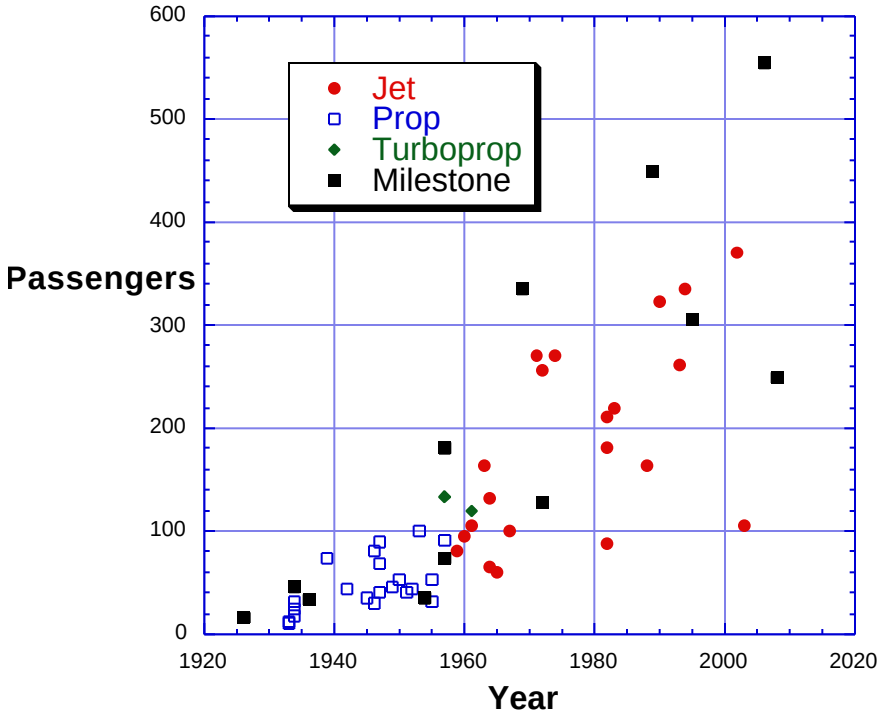
Growth of Air Transport Speed and Passengers

- Milestone Aircraft
  - Ford Tri-Motor (1926)
  - Martin M-130 (1934)
  - Douglas DC-3 (1936)
  - Boeing 307 (1936)
  - deHavilland Comet (1954)
  - Lockheed Electra (1957)
  - Boeing 707 (1957)
  - Boeing 747 (1969)
  - BAC/SA Concorde (1972)
  - Boeing 777 (1995)
  - Boeing 747-400 (1989)
  - Airbus A-380 (2006)
  - Boeing Sonic Cruiser (2008)

Cruising Speed vs. Year



Maximum Passengers vs. Year



Growth of Air Transport Range and Weight

- Milestone Aircraft
  - Ford Tri-Motor (1926)
  - Martin M-130 (1934)
  - Douglas DC-3 (1936)
  - Boeing 307 (1936)
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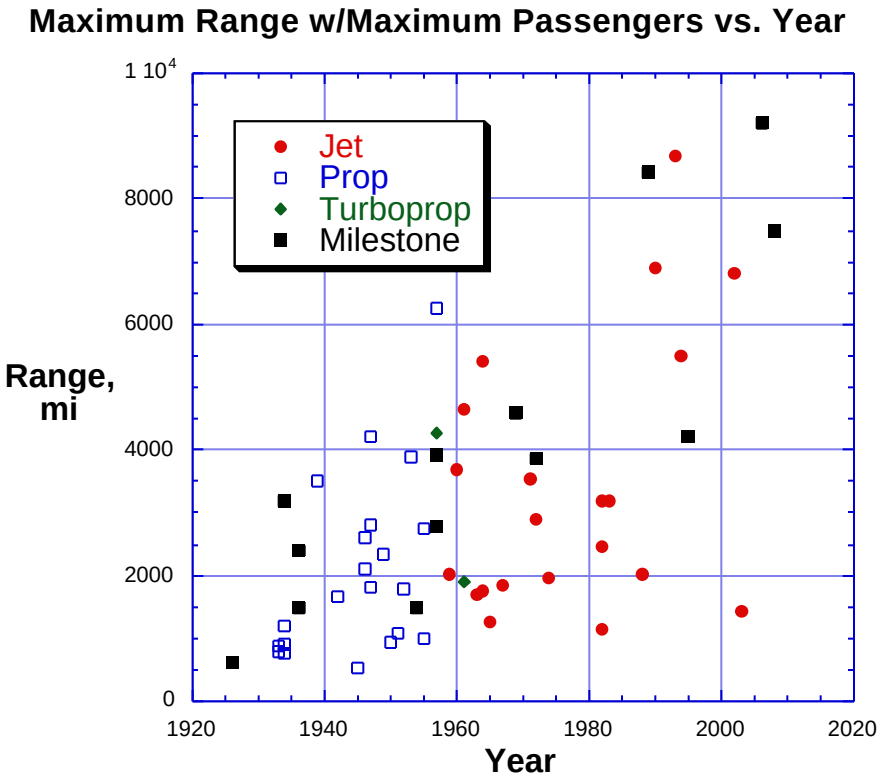

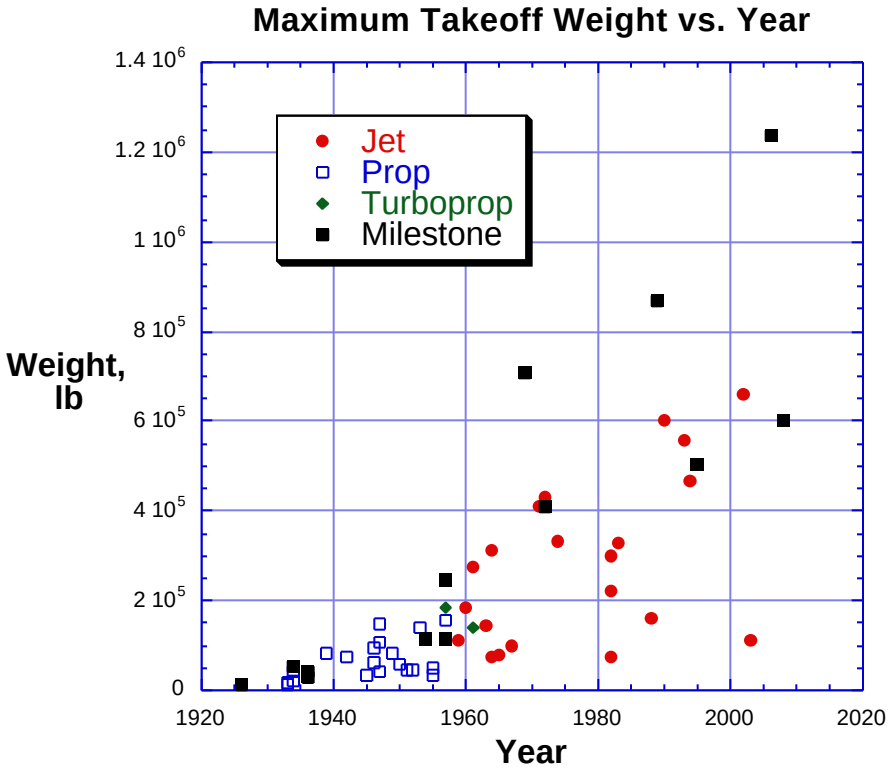

Growth of Air Transport Productivity

- Milestone Aircraft
  - Ford Tri-Motor (1926)
  - Martin M-130 (1934)
  - Douglas DC-3 (1936)
  - Boeing 307 (1936)
  - deHavilland Comet (1954)
  - Lockheed Electra (1957)
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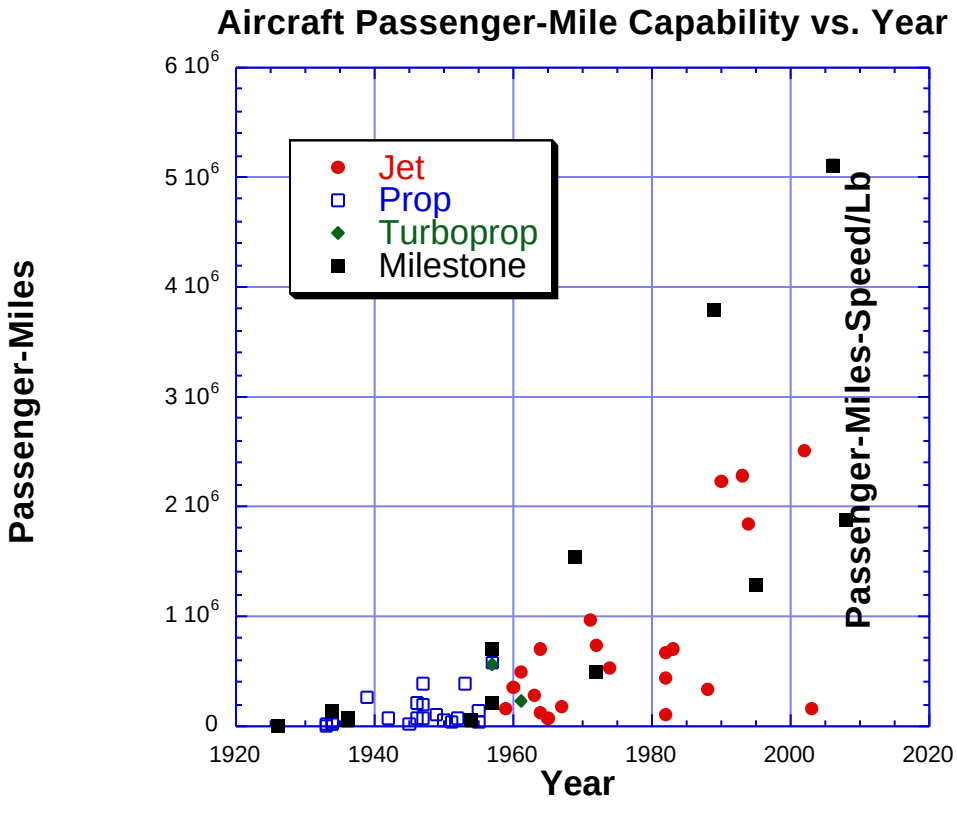
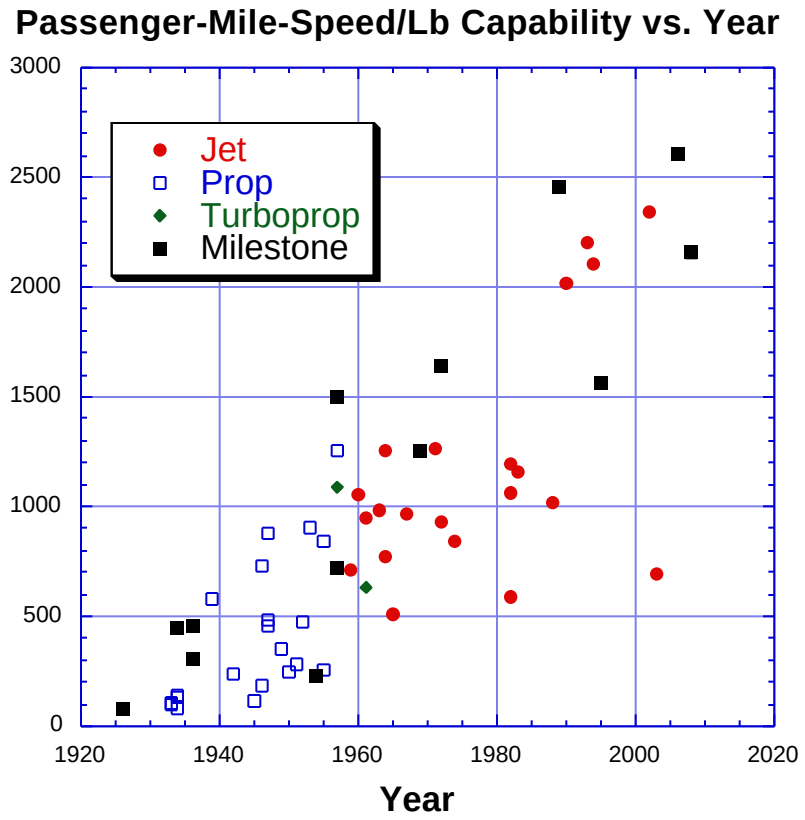
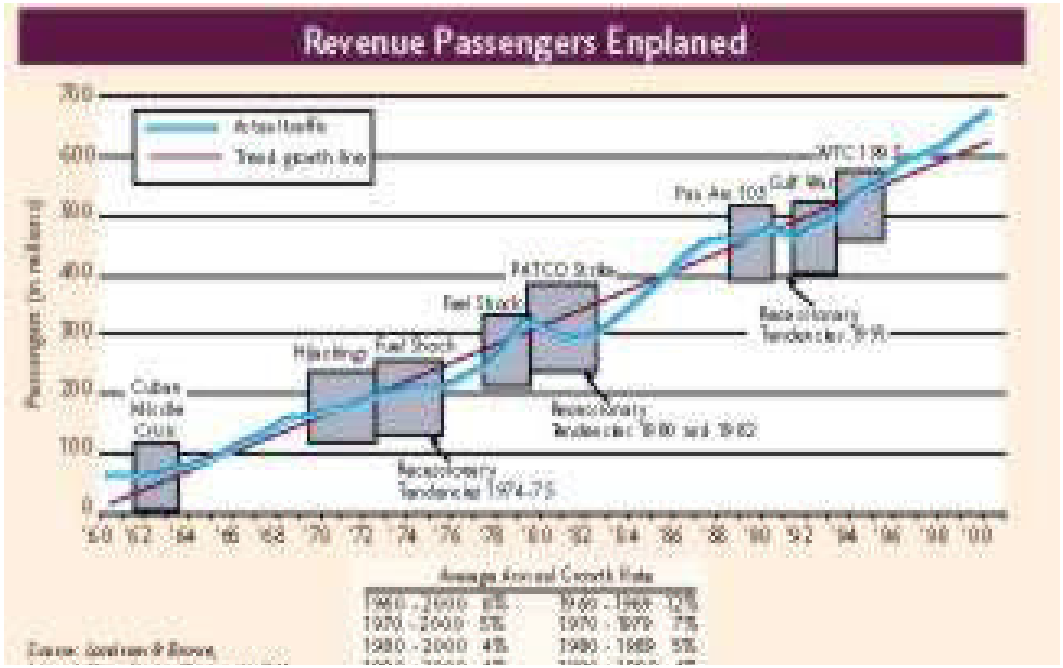


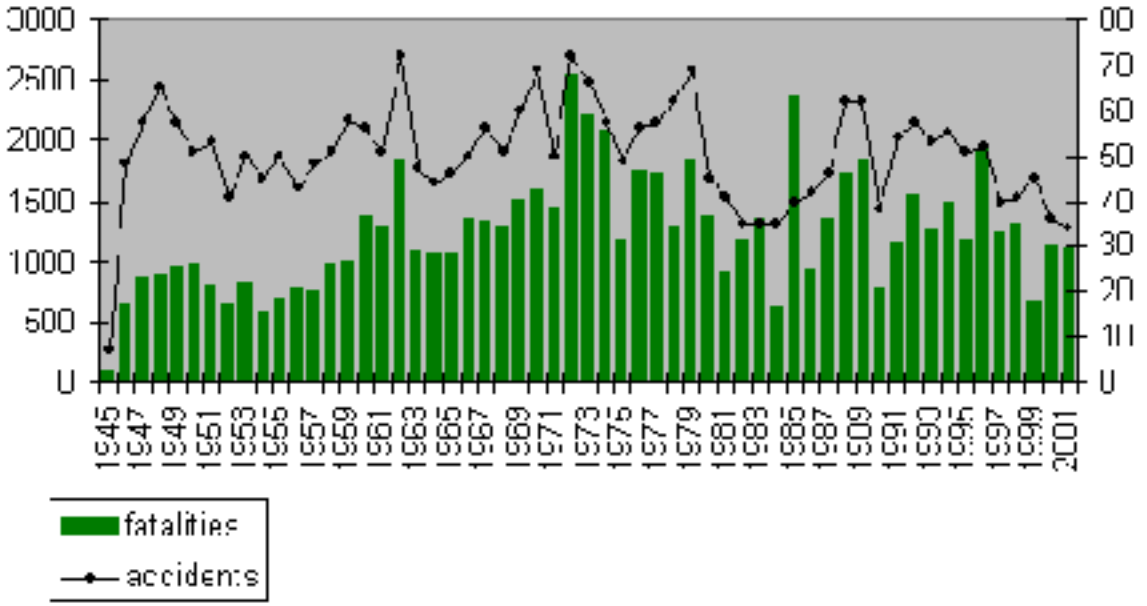


Scope and Safety of Commercial Air Transportation

- Passenger-emplanement increase since 1962



- Increasing safety over the period
- Decreasing accidents and fatalities with increasing flights and emplanements



... but it still takes longer to fly from one place to another

- In spite of increased aircraft speed capabilities, block times (flying times in segments between takeoff and landing) have increased due to
  - increased traffic
  - inadequate growth in air traffic control capabilities