Aircraft Design
Case Studies

Aviation Timeline

December 17, 1903	**Wright Flyer (first powered aircraft flight)**
December 1913	**Curtiss Pusher and Christopherson Biplane (first aerial dogfight)**
January 1, 1914	**Benoist XIV biplane flying boat (first scheduled commercial flight)**
August 2, 1917	**Sopwith Pup (first landing on a moving ship)**
June 27, 1923	**Airco DH-48 (first aerial refueling)**
August 27, 1939	**Heinkel HE-178 (first jet engine flight)**
October 14, 1947	**Bell X-1 (first flight to exceed the sound barrier)**
January 21, 1976	**Concorde (first supersonic scheduled commercial flight)**
December 14-23, 1986	**Rutan Voyager (first non-stop unrefueled flight around the world)**

UNIVERSITY OF Cincinnati

Collier Trophy

1947	Chuck Yeager, Bell X-1 (breaking the sound barrier)
1958	Kelly Johnson / Lockheed Skunk Works, F-104 Starfighter
1963	Kelly Johnson / Lockheed Skunk Works, SR-71 Blackbird
1970	Boeing 747
1975	General Dynamics F-16 Falcon
1982	Boeing 757 and 767
1989	Ben Rich / Lockheed Skunk Works, F-117 Nighthawk
1990	Bell Boeing V-22 Osprey
1991	Northrop B-2
1994	McDonnell Douglas C-17 Globemaster III

Collier Trophy

1995	Boeing 777
1996	Cessna Citation X
2000	Northrop Grumman RQ-4 Global Hawk
2001	Joint Strike Fighter, X-35 Integrated Lift Fan Propulsion System
2003	Burt Rutan, SpaceShipOne
2004	Gulfstream G550
2006	Lockheed F-22
2011	Boeing 787
2013	Northrop Grumman X-47B
2014	Gulfstream G650

Inspiring Aircraft

2001 Collier Trophy
Integrated Lift Fan
Propulsion System

UNIVERSITY OF Cincinnati

X-45/X-47 Program

Design Study #1

Subsonic / Transonic Jet Aircraft

Design evolution of the first civil jet airliner – Boeing 707

Start with Boeing's experience – earlier designs of B-47 and B-52

Why?

B-47 = revolutionary design!

Late 1943 – study contract issued by Wright Field

- **North American, Convair, and Boeing**
- **design a jet-powered bomber; 80,000 to 200,000 lb**
- **use the newly designed GE TG-180 engine**

Army Air Corps selected the North American B-45

UNIVERSITY OF Cincinnati

Design Study #1

North American B-45 first flight in March 1947
North American built 142 aircraft for USAF and Royal Air Force

UNIVERSITY OF Cincinnati

Design Study #1

What does this have to do with the Boeing 707?

Boeing aerodynamicists weren't satisfied with their bomber design
- **Critical Mach number was too low**
- **Engines faired into the wing caused too much drag**

May 1945 – U.S. technical intelligence team found German wind tunnel test data for swept wings

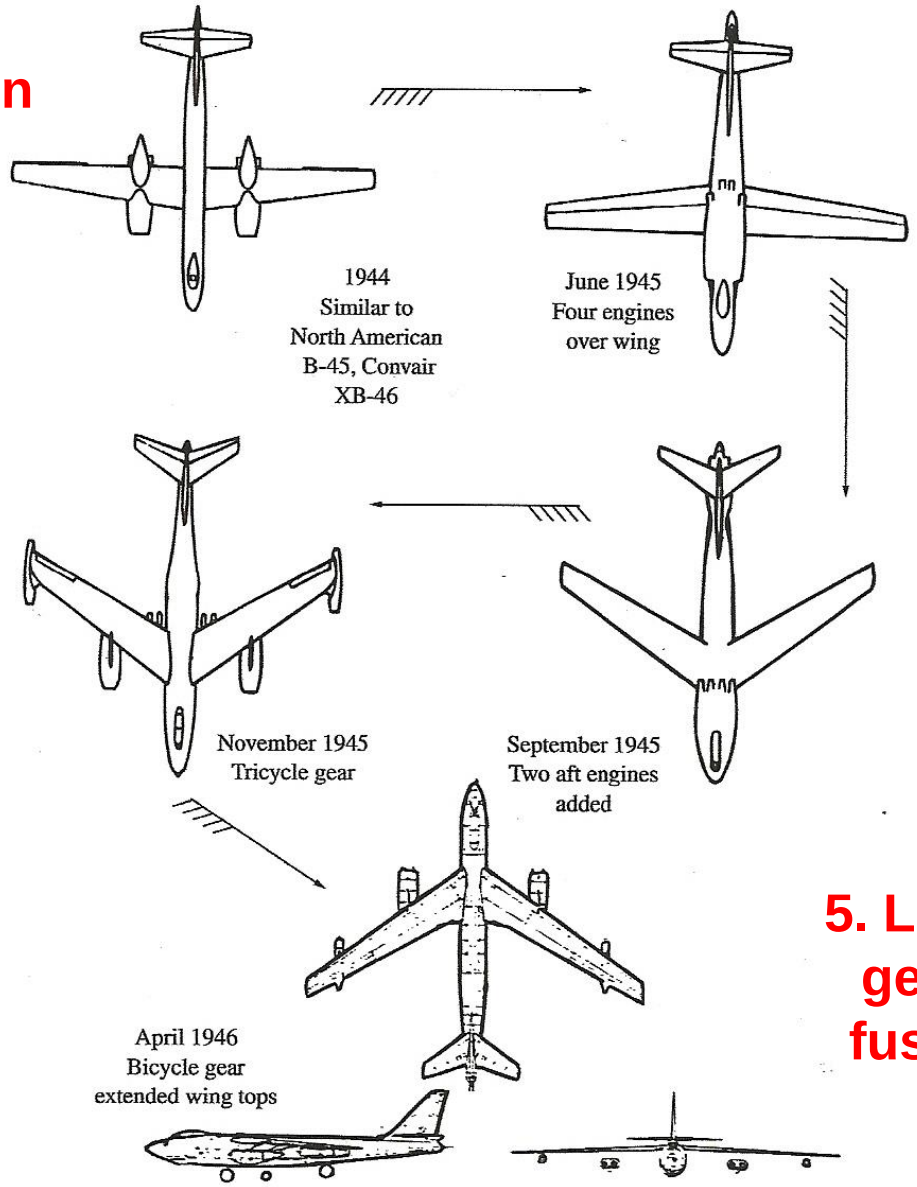
Boeing engineers scrapped their straight wing designs for swept wing wind tunnel testing

Boeing spend the next several months re-designing their jet engine bomber with swept wings

UNIVERSITY OF Cincinnati

1. Losing design

2. Moved engines to fuselage



4. Engines below the wing on struts

3. Swept wings

5. Landing gear on fuselage

Figure 9.2 The design evolution of the Boeing B-47. (*From Cook, Ref. 63, with permission.*)

UNIVERSITY OF Cincinnati

Design Study #1

October 1945 – Boeing engineers designed the first aircraft with the engines mounted below the wing on struts

December 1947 – First flight of the XB-47

September 1948 – USAF picked the B-47 as their new jet bomber

2,032 B-47s were built and put into service

UNIVERSITY OF Cincinnati

Design Study #1

What was so revolutionary about the B-47 design?

The clean, thin, aerodynamic, high Aspect Ratio wing

- **Higher L / D**
- **Lower drag-due-to-lift**

The 35 degree Wing Sweep

- **Higher Drag Divergence Mach Number**
- **Higher cruise speeds**

Large fuel capacity – Fuel Fraction over 50%

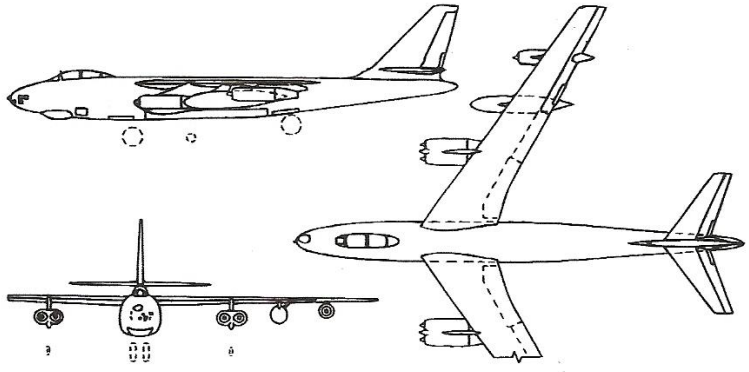
$$R = \frac{V}{c_t}\frac{L}{D}\ln\frac{W_0}{W_1}$$

UNIVERSITY OF Cincinnati

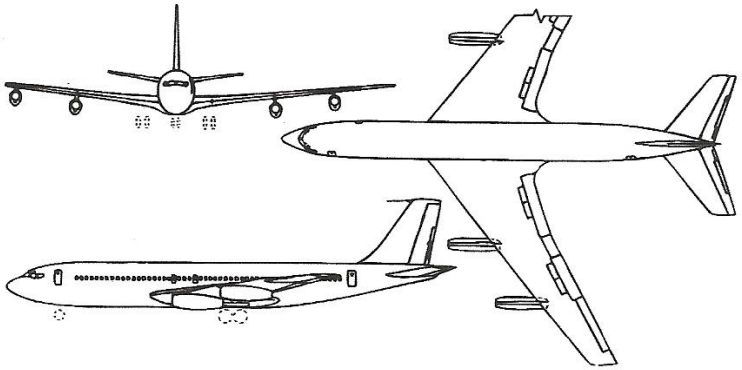
Design Study #1

Again, what does this have to do with the Boeing 707?

Boeing engineers evolved the B-47 configuration to the 707



Boeing B-47



Boeing 707

Figure 9.4 Three-views of the Boeing B-47 and 707, for comparison.

- **Different landing gear (stow under center fuselage)**
- **Low wing placement (long body deck for passengers)**
- **Added spoilers and ailerons (better lateral control)**

UNIVERSITY OF Cincinnati

Design Study #1

Again, what does this have to do with the Boeing 707?

Boeing's first attempt at non-military aircraft market

Boeing 707 First Flight – July 15, 1954

First 707 deliveries to Pan Am Airlines – September 1958

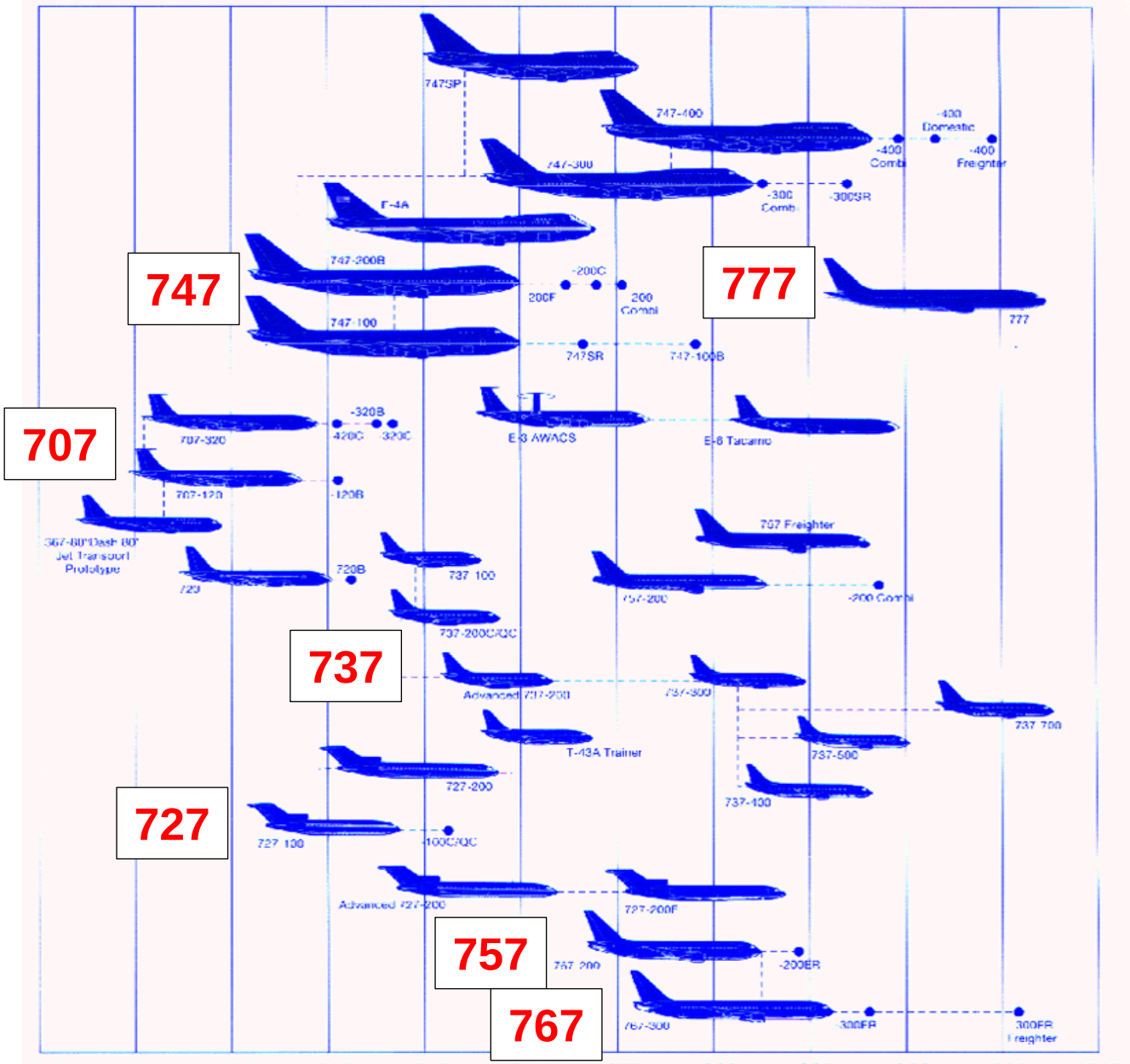
Boeing built and delivered 1,010 707s over 35 years

The Boeing 707 became the first successful jet airliner

Boeing then used this experience to design the 727, 737, etc ...

UNIVERSITY OF Cincinnati

Boeing Commercial Airplane Parade of Progress



NOTE: Nose Position or - - - ●Indicates First Delivery

UNIVERSITY OF Cincinnati

Design Study #2

Lightweight Supersonic Fighter Aircraft

First study contracts were issued in the late 1960s

Original requirements:
Highly maneuverable, lightweight fighter aircraft
Maximize usable maneuverability and agility in the air combat arena
Emphasis on small size and low weight/cost design techniques

Why?
Fighter aircraft (F-4, F-14, F-15) were getting heavy and costly

Reasons:
Smaller and lighter = greater maneuverability
Smaller and lighter = less total cost
Smaller and lighter = smaller Radar Cross Section for detection

UNIVERSITY OF Cincinnati

Design Study #2

Lightweight Supersonic Fighter Aircraft

April 14, 1972 – Prototype contracts awarded

- **General Dynamics (YF-16)**
- **Northrop (YF-17)**

1974 – Flight testing of two YF-16s and two YF-17s

January 13, 1975 – General Dynamics F-16 Falcon was selected

UNIVERSITY OF Cincinnati

Design Study #2

Lightweight Supersonic Fighter Aircraft

F-16 Fighting Falcon

Over 4,500 F-16s have been built and delivered since 1976

Bought by 25 other countries

F-18 Hornet

Nearly 1,500 F-18s have been built and delivered since 1978

Bought by 7 other countries

UNIVERSITY OF Cincinnati


UNITED STATES AIR FORCE
USAF


US NAVY

Design Study #3

Lockheed Martin F-22 Raptor

First study contracts were issued in September 1983

Original requirements:
Max Takeoff Gross Weight < 50,000 lb
Mission Radius > 800 NM
Supersonic cruise speed > 1.5 M without afterburner
Able to use 2,000 ft runway (changed to 3,000 ft later)

Airframe Contractors:

Lockheed	**Northrop**	**Grumman**
General Dynamics	**McDonnell Douglas**	**Rockwell**
Boeing		

YF-22 **YF-23** **October 1986**
50 month Demonstration and Validation Phase

UNIVERSITY OF Cincinnati

Design Study #3

Lockheed Martin F-22 Raptor

50 month Demonstration and Validation "fly before you buy" Phase

- **19,000 hours of wind tunnel testing**
- **Instrumented engines**
- **74 flights and 92 flight hours of testing**
  (YF-23 – 50 flights and 65 hours)
- **"Sealed Envelope" pre-flight performance predictions**

UNIVERSITY OF Cincinnati

Design Study #3

Design Study #3

Lockheed Martin F-22 Raptor

The F-22 was selected on April 23, 1991

F-22 First Flight – September 7, 1997

195 F-22s were built and delivered to the USAF

UNIVERSITY OF Cincinnati

More Information

Reading – Chapters 8 and 9

Questions?