Introduction to aeronautics

Part 4. The era of the jet-propelled airplane

4.4 The design for breaking sound barrier

- **Flutter**
  - **Ballast is used to eliminate flutter**

4.4 The design for breaking sound barrier

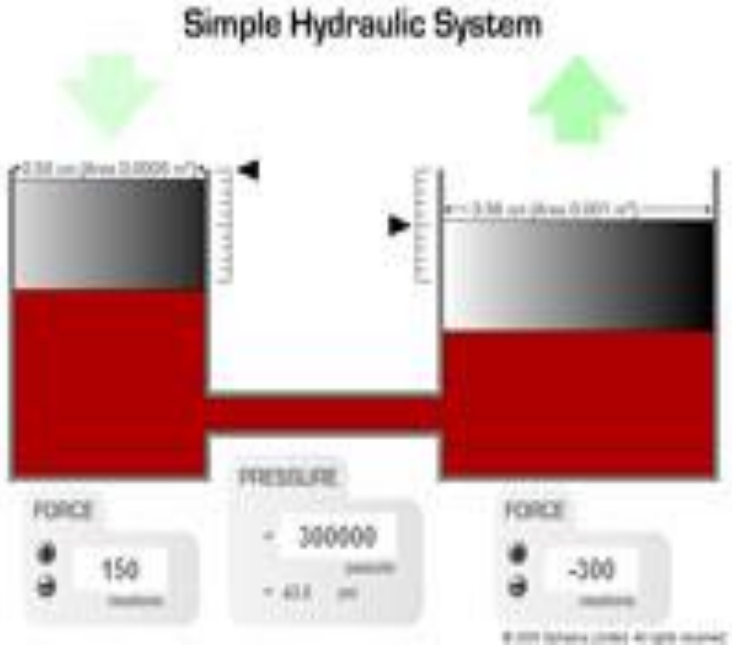
- **Flutter**
  - **The wing tip missile can eliminate flutter**

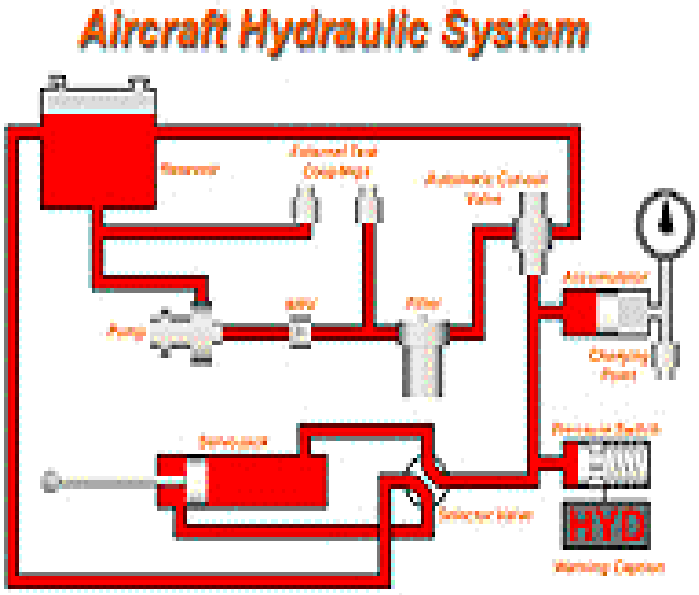
4.5 The flight control system

- **Mechanical control system**
  - **The control surfaces are moved by cable, pushrods**
  - **Used by low speed and small aircraft**

4.5 The flight control system

- **Hydro-Mechanical control system**
  - **Used by high speed and large aircraft**
  - **The control surfaces are moved by hydraulic system**
  - **Artificial feel devices and stick shaker is required**





4.5 The flight control system

- **Fly-By-Wire system**
  - **The control command is transferred into electrical signal and transmitted by wires**
  - **The flight control computers will decide how to move the actuators**

5. The evolution of the fighter planes

1. Fighter planes

The invention of jet engines lead to the world's 1st generation fighter planes

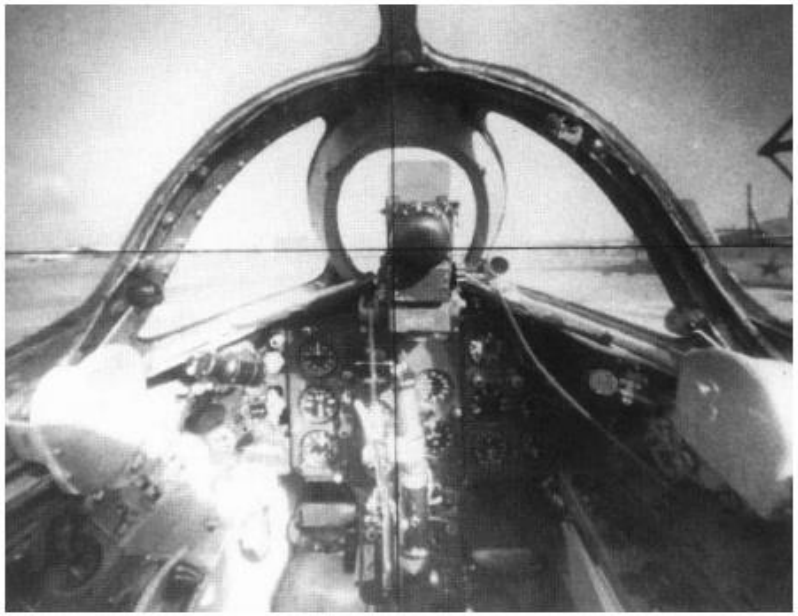
5. The evolution of the fighter planes

- **Features of 1st generation fighters**
  - **Equipped with canons and rockets as primary weapon, Some of them can launch the 1st generation AAM**

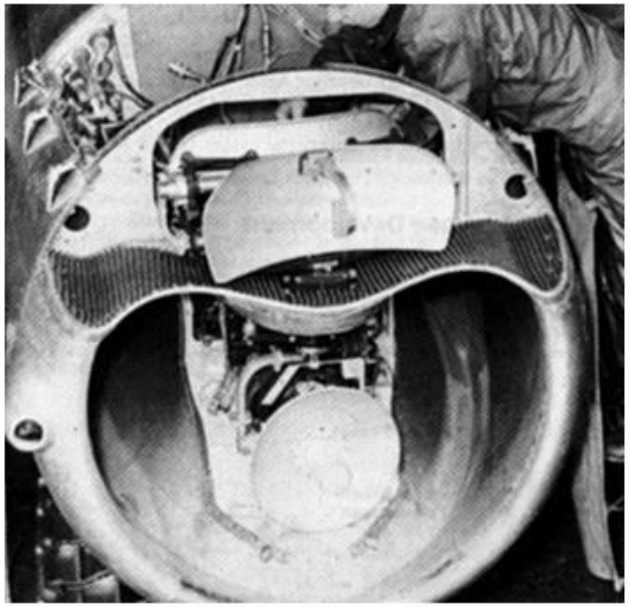
Kaliningrad K-5M (NATO: AA-1 "Alkali") missiles

5. The evolution of the fighter planes

- **Features of 1st generation fighters**
  - **Equipped with simple radar and optical gun sight**



Cockpit of Mig-19

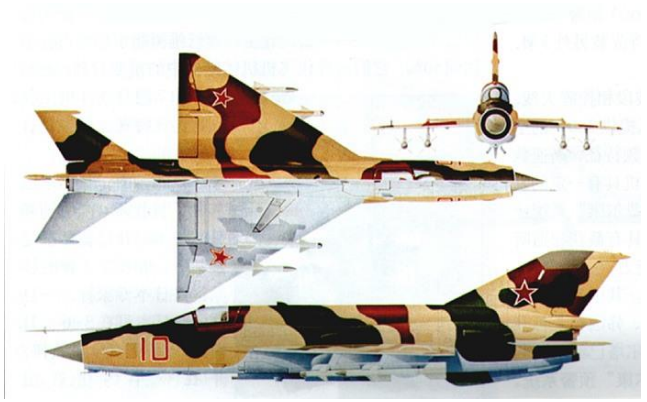


RP-1 Izumrud radar

5. The evolution of the fighter planes

1. **Fighter planes**

- **The experiences from Korean war and the advancement of technology leads to 2nd generation fighter planes**



5. The evolution of the fighter planes

- **The design philosophy behind the 2nd generation fighter planes**
  - **Aircraft with high speed will win the battle**
  - **AAMs will replace cannons. Therefore high speed is much more important than high maneuverability**
  - **Tactical bombers are slow and vulnerable. It needs escort planes, which is not efficient. Therefore multi-purpose fighters or fighter-bombers are preferred**
  - **Shall deploy interceptors with high speed and AAMs to attack nuclear bombers. Try to win the battle with one approach**

5. The evolution of the fighter planes

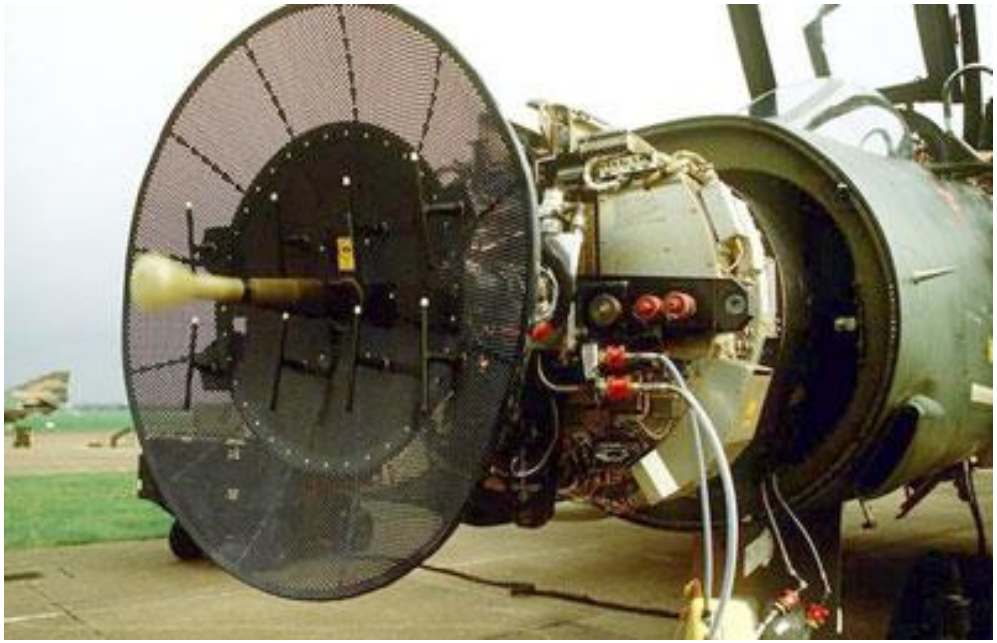
- **The features of the 2nd generation fighter planes**
  - **Delta wings are very popular. Maneuverability is neglected. Maximum speed reaches Ma 2.0**

5. The evolution of the fighter planes

- **The features of the 2nd generation fighter planes**
  - **Multi-role fighters are favored**
  - **Some of them were not equipped with cannon, but totally counted on AAM.**

5. The evolution of the fighter planes

- **The features of the 2nd generation fighter planes**
  - **Some of them were equipped with on-board fire control computers, PD radar and CRT display**



5. The evolution of the fighter planes

1. **Fighter planes**
   - **The bloody Vietnam war and the new technologies leads to the 3rd generation fighter planes**

5. The evolution of the fighter planes

- **The design philosophy behind the 3rd generation fighter planes**
  - **The development of SAM makes high altitude bombing dangerous. Low altitude cruise is preferred**
  - **The air combat during Vietnam war occurs at sub-sonic speed and altitude from 1500m to 4500m. Dog fights are very common. Therefore the aircraft must have high maneuverability at subsonic speed**
  - **Cannon is essential for wining the combat**

5. The evolution of the fighter planes

- **The features of the 3rd generation fighter planes**

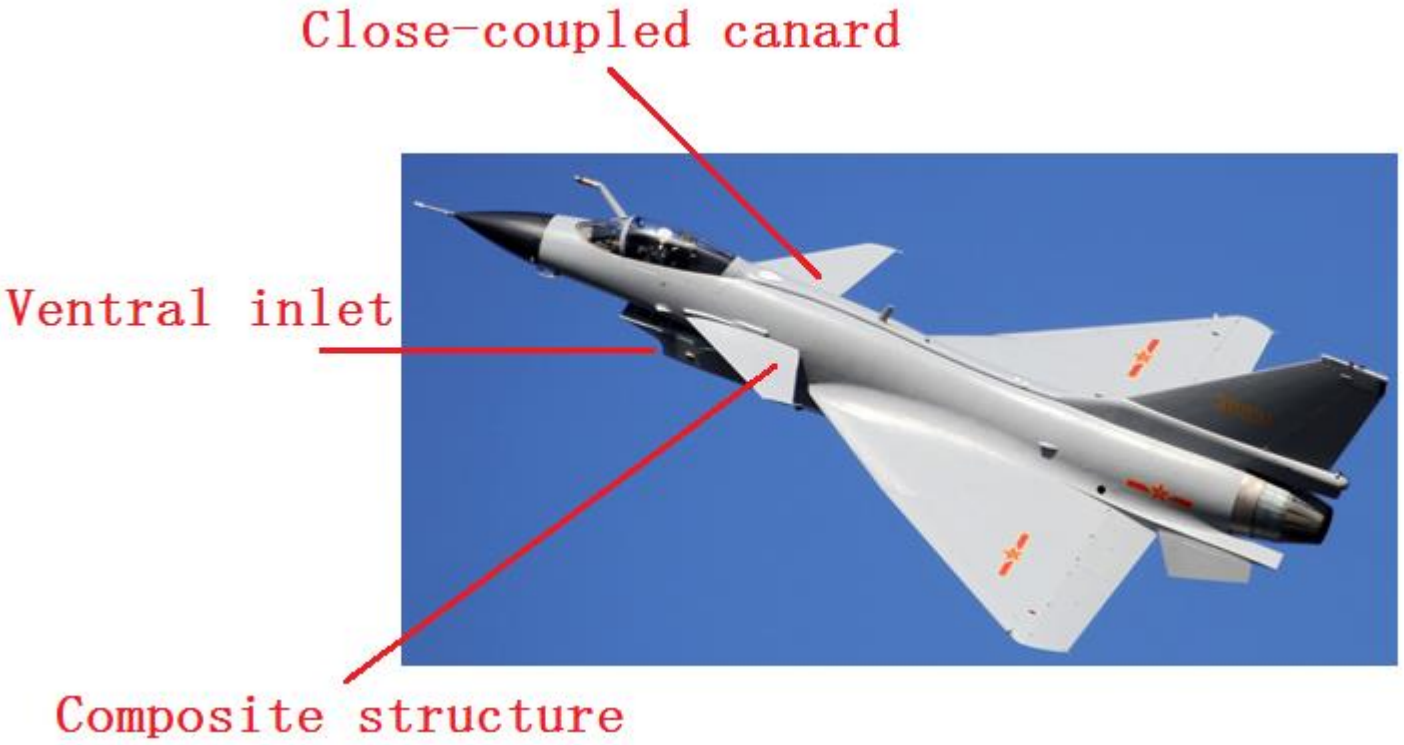
·FBW system
·CCV
·Aircraft thrust to weight ratio greater than 1.0
·Relaxed static stability
·Larger fuel fraction
Engines with thrust to weight ratio greater than 8

LEX

Wings with smaller Leading edge sweep back angle and larger A.R.

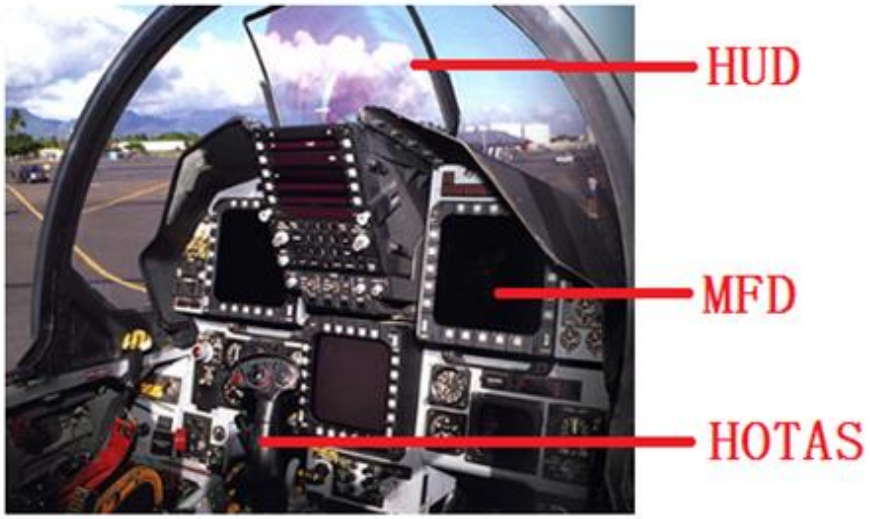
5. The evolution of the fighter planes

- **The features of the 3rd generation fighter planes**



5. The evolution of the fighter planes

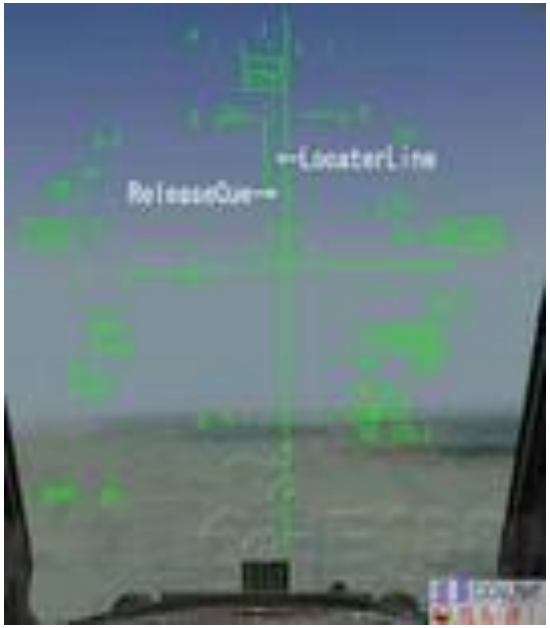
- **The features of the 3rd generation fighter planes**



·INS
·TACAN
·ILS
·Infrared Search and Track

Versertile PD radar
(AGP-70)

HUD and MFD


←LocaterLine
ReleaseCue→


DEP DCPL
CNTL
GAIN
SYM
BRT
CON
SWAP SMS DTE HSD S-J

HOTAS


BTN T2
/H SpeedDec
BTN T4
VNAV
BTN T5
LNAV
T2
T5
T4
T3
T6
BTN T6
Spot
BTN T3
/H SpeedInc
BTN T7
Levelchange
T7
T8
T10
T9
BTN T8
/P /R Approachmode
BTN T10
/P /R Parkingbrakeonoff
BTN T9
SpeedbrakeArm
T1
BTN T1
Radiostac
MIX
5 3 (0 5 95 100) (SHF 7) ^ (SHF 5)
MIY
5 3 (0 5 95 100) (SHF 2) ^ (SHF 6)
Hat 2
U: /H Elevatortrimdown
L: /H HeadingBugDec
R: /H HeadingBugInc
D: /H Elevatortrimup
Triggers
TG1 /H Brakes
TG2 Landinggear
Hat 4
U: Flapsretract
L: Flapsretractfully
R: flapsextendfully
D: Flapsextend
BTN S3
Landinglightonoff
BTN S4
AutothrottleOnOff
BTN S2
Autopilotoff
S2
H1
S1
H2
H3
Triggers
TG1, TG2
H4
S3
S4
BTN S1
Flightdirectoronoff
Hat 3
U: /H AltitudeInc
L: /H CourseDec
R: /H CourseInc
D: /H AltitudeDec
PARKING BRAKES - Press PERIOD (.) to release.

5. The evolution of the fighter planes

1. **Fighter planes**

- **The stealth technology, advanced jet engine and modern avionics leads to the 4th generation fighter planes**

5. The evolution of the fighter planes

- The features of the 4th generation fighter planes
  - Stealth
    - Infra red stealth
    - Radar stealth
    - Visual stealth
    - Aural stealth

• Infrared stealth

- **The most effective approach is to reduce engine IR signal from engine**
  - **Approach 1: High bypass ratio engine**
  - **Approach 2: Try to cover/hide the exhaust nozzle**
  - **Approach 3: Use rectangle or slit nozzle**
  - **Approach 4: Circulate coolant fluids, such as fuel, cool air, to absorb heat**
  - **Apply coating to reduce the IR signal**

• Infrared stealth

A-10

- TF34 High BPR engine
- Vent the nozzle by HT/VT

B-2

- Slit nozzle
- Exhaust nozzle above the wing
- Cool down the engine temperature with cold air taken from wing surface

• Radar stealth

- Radar stealth is achieved primarily by reducing RCS
  - Cross-sectional area of a perfectly reflecting sphere that would produce the same strength reflection as would the object in question
  - Unit: m^2, dbsm

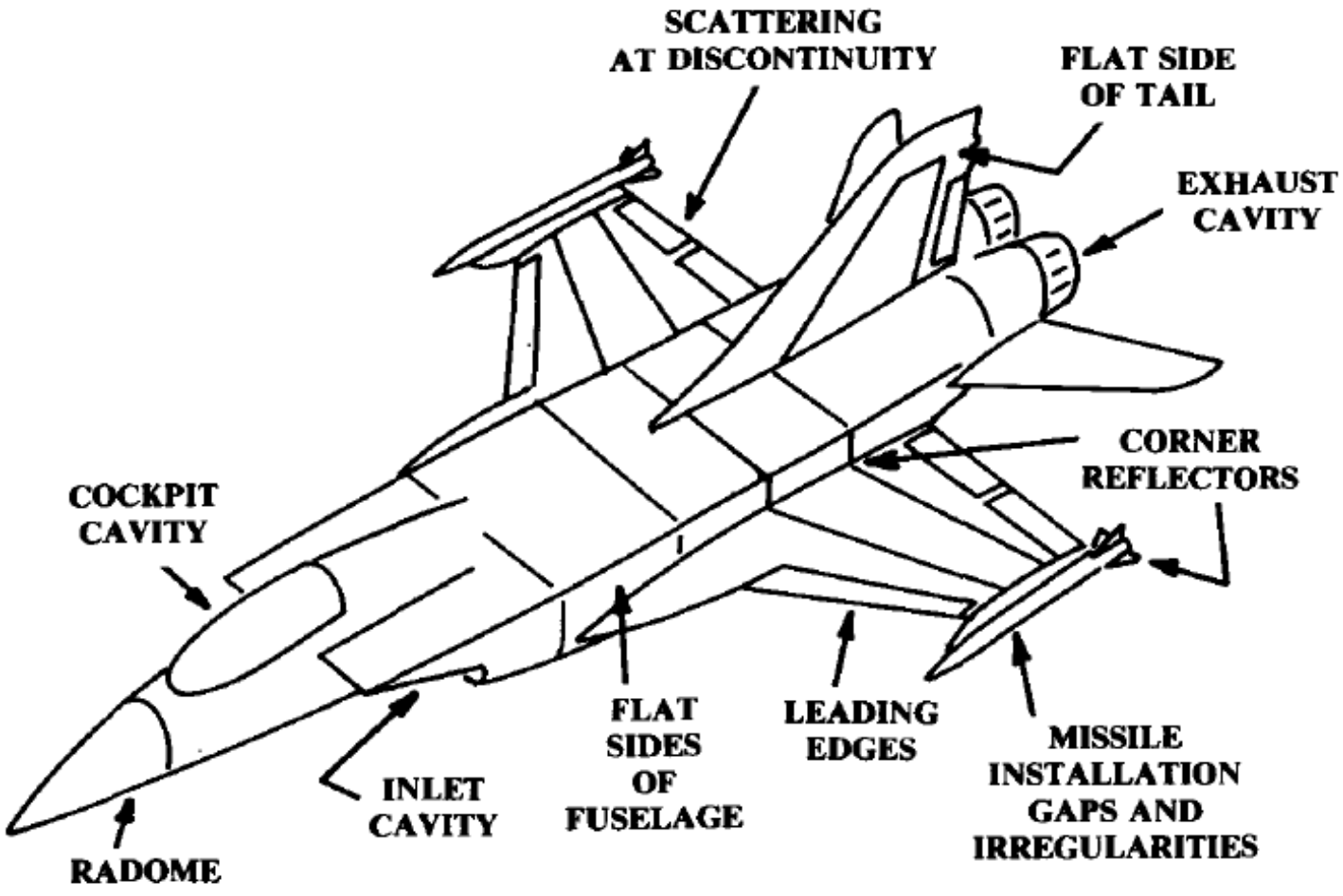
$$\sigma[dB(m^2)] = 10 \times \lg RCS[m^2]$$

0dbsm → $10^0 = 1m^2$

20dbm → $10^2 = 100m^2$

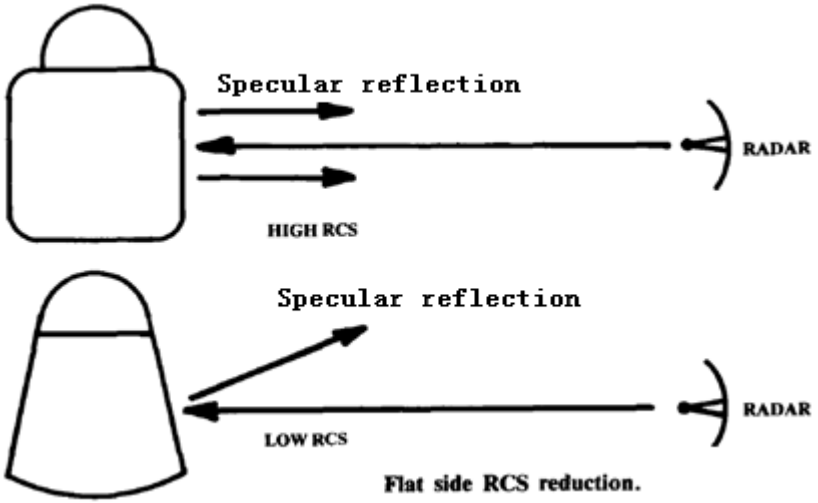
  - Radar reflection is proportional to
    If RCS reduces 90%, the detection range reduces less than a half ($\sqrt[4]{0.1} = 0.56$)
  - The RCS increases, the detectability increses as well
  - RCS is not the actual cross section of the object

- **Radar stealth**

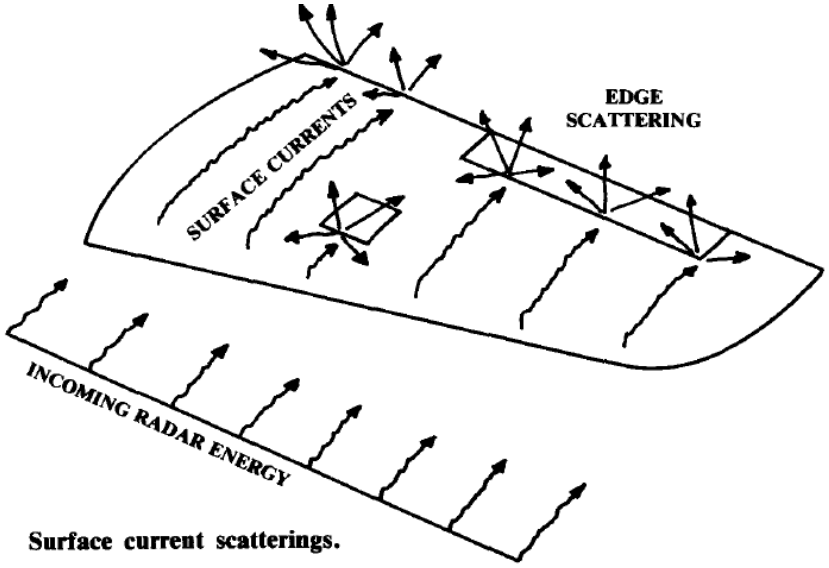


Major RCS contributors

- **Radar stealth**



Flat side RCS reduction.



Surface current scatterings.

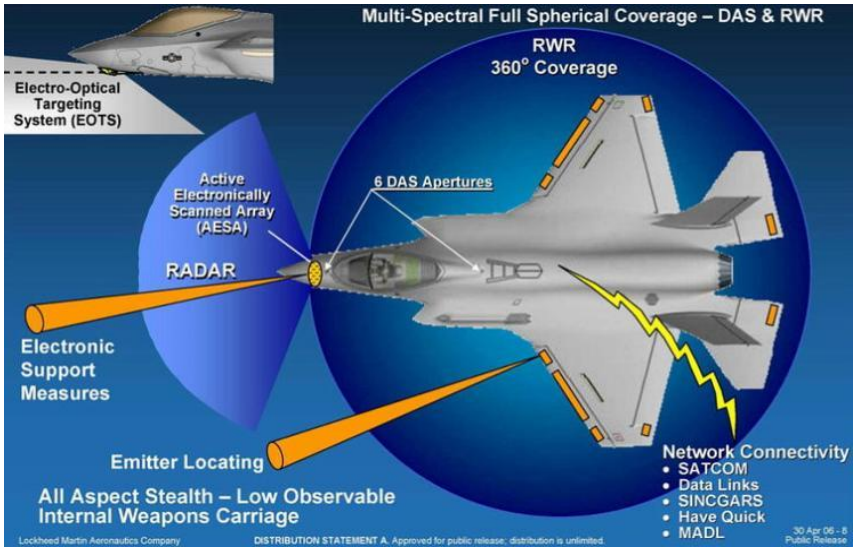
- **Radar stealth**

1. The way to reduce RCS

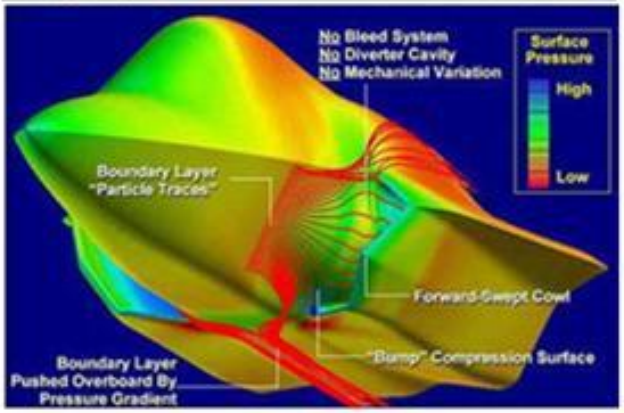
- Tilt the vertical stabilizer or remove stabilizer
- Use “S” inlet duct or fine mesh screen to shield the fan
- Use rectangle/slit jet exhaust
- Apply iridium tin oxide coating on canopy




- **Radar stealth**
  - **Frequency Selective Surfaces (FSS)**
  - **Hide missiles into internal weapon bays**
  - **Mount conformal antenna**



- **Radar stealth**
  - **Replace conventional air intake by DSI air intake**



- **Radar stealth**

- **Tilt both sides of fuselage**

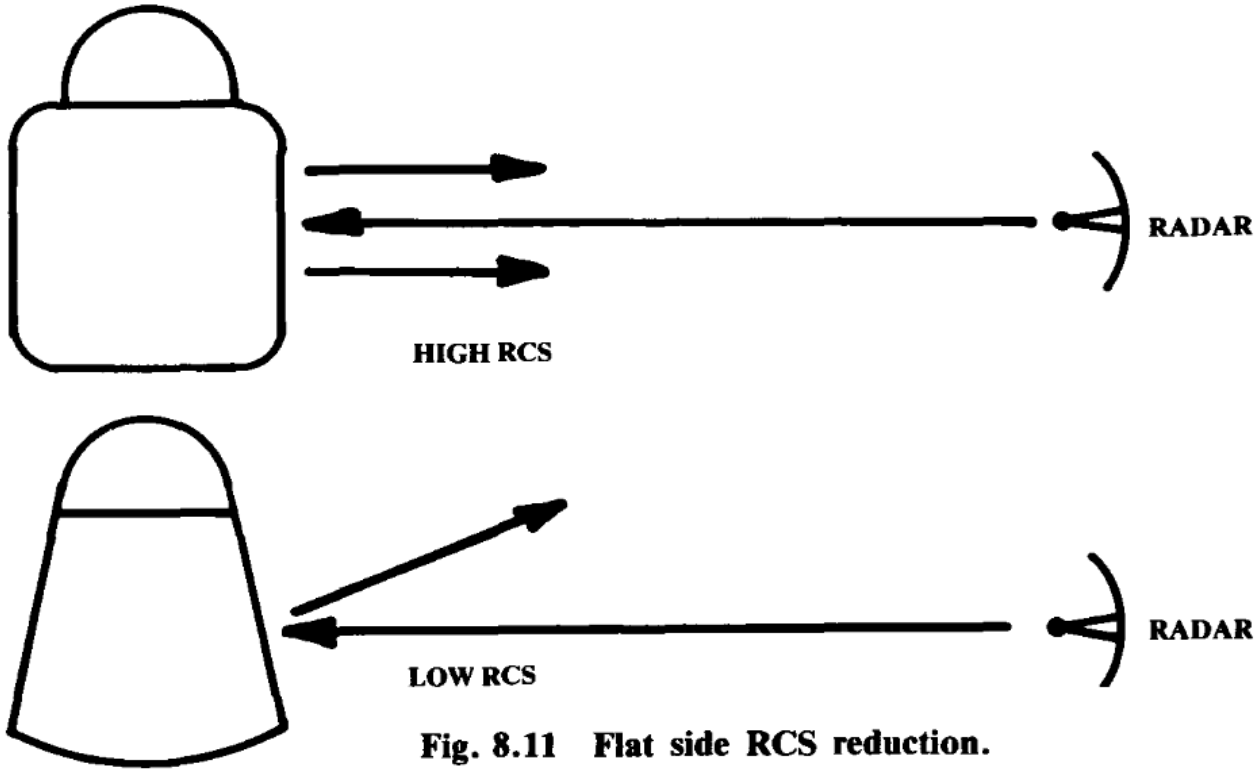
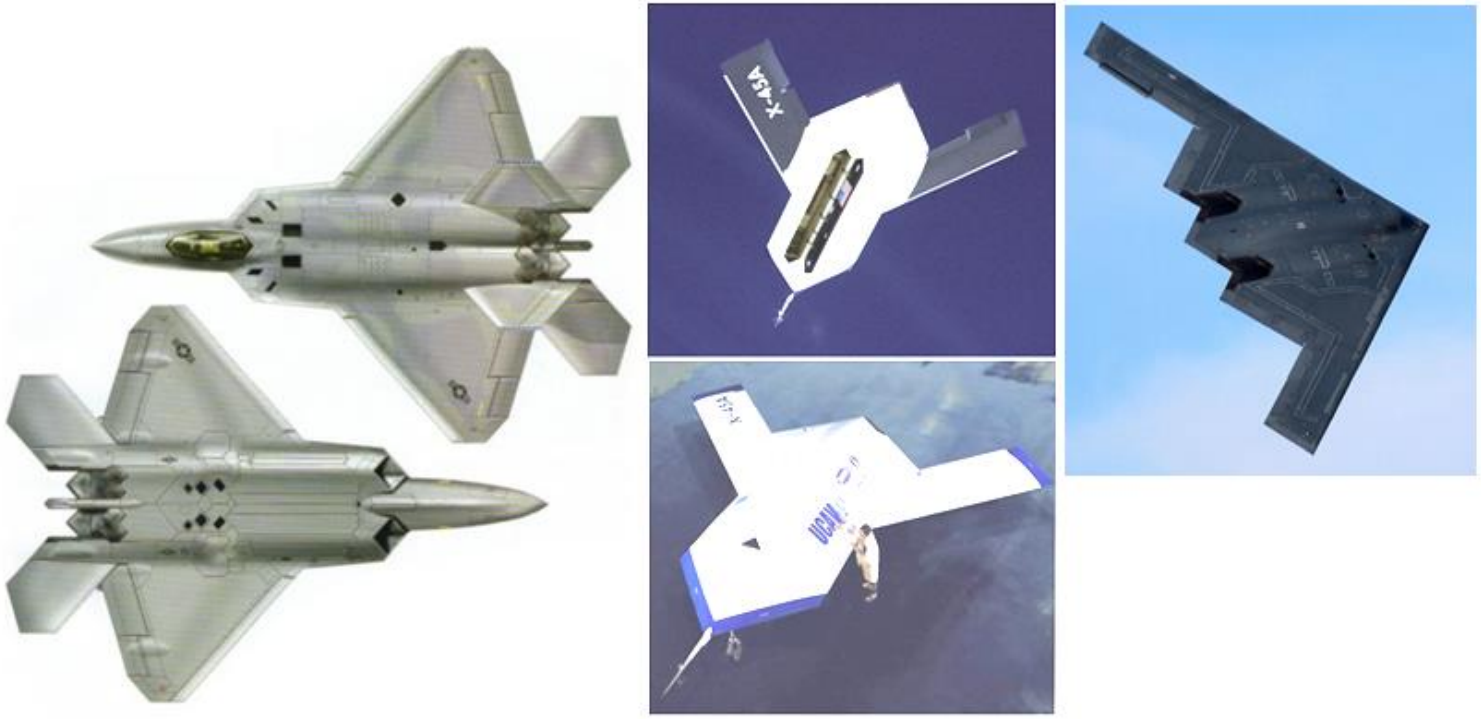


Fig. 8.11 Flat side RCS reduction.

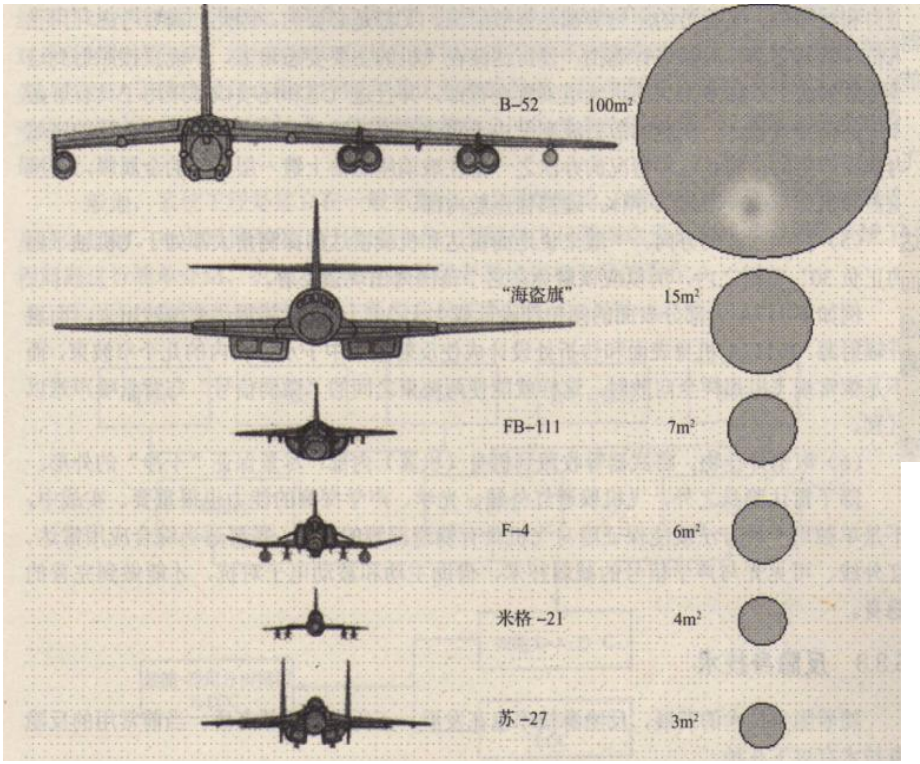
- **Radar stealth**
  - **Reduce reflection caused by creeping wave in the skin**
    • Swept back/forward leading edge/trailing edge
    • Saw tooth on the edge of openings and doors

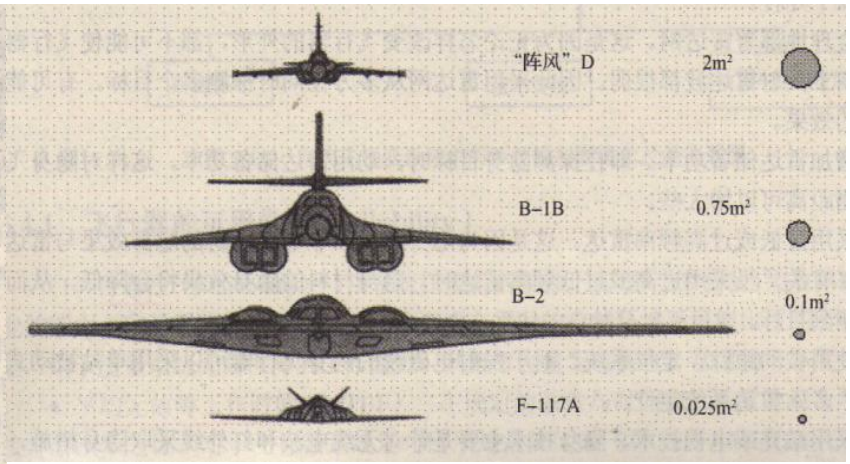
- **Radar stealth**
  - **Limit reflection waves into a few direction**
    - **Try to make all leading edge and trailing edge parallel to each other**



- **Radar stealth**
  - **Apply radar-absorbent material on the aircraft（Iron ball paint . Etc.)**

- **Radar stealth**
  - **The effect of radar stealth technology**





5. The evolution of the fighter planes

- **Super maneuverability**
  - **Relaxed static stability (Statically unstable) and FBW**
  - **LEX**
  - **Vectored thrust**
  - **Advanced engine with thrust to weight radio as high as 10**

5. The evolution of the fighter planes

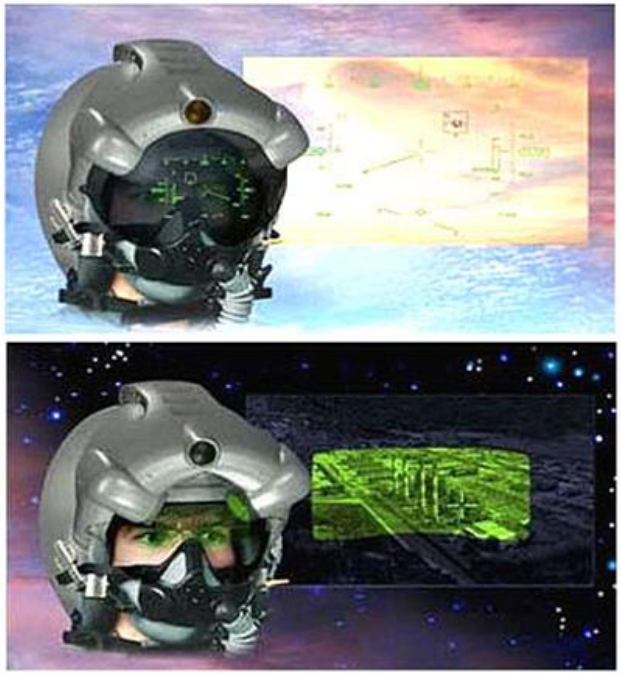
- **Superior Avionics for Battle Awareness and Effectiveness**
  - **Multi function phased array radar**
  - **Sensor fusion incorporates information from different types of sensor and enables pilots to focus on tactics and mission**

5. The evolution of the fighter planes

- **Superior Avionics for Battle Awareness and Effectiveness**
  - **Avionics of F-35:**
    - **EOTS (Electro-Optical Targeting system)**
    - **AN/AAQ-37 distributed aperture system (DAS)**
    - **Multifunction Advanced Data Link (MADL)**

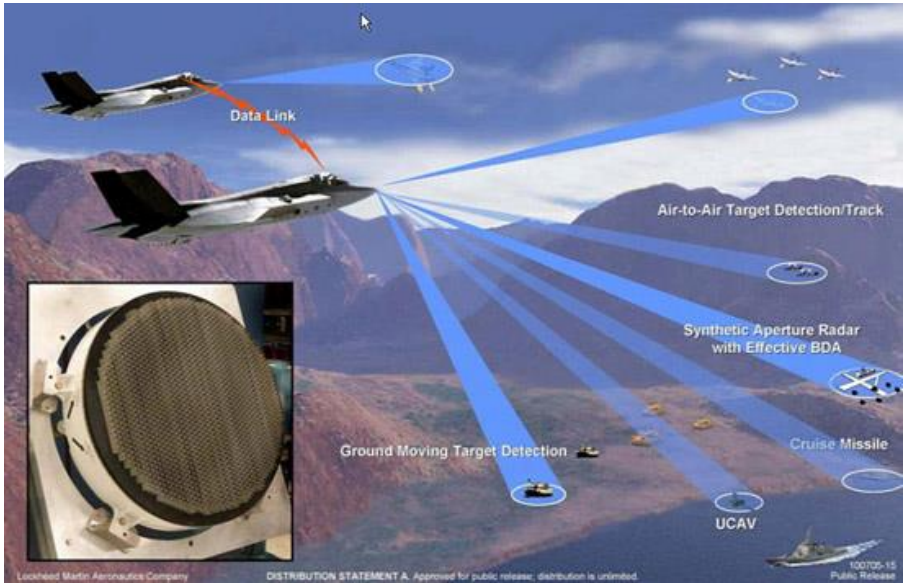
5. The evolution of the fighter planes

- **Avionics of F-35:**
  - **User friendly MFD**
  - **Head mounted display system to replace HUD**



5. The evolution of the fighter planes

- **Avionics of F-35:**
  - **Versatile and powerful AN/APG-81 Radar**
    - **Data link**
    - **Air to air target detection/track**
    - **Synthetic aperture radar for topographic mapping**
    - **Ground target detection**



5. The evolution of the fighter planes

- **Supersonic cruise**
  - **Advanced aerodynamics configuration**
  - **All weapons are in the weapon bay**
  - **Powerful engines with thrust to weight ratio as high as 10**
  - **Multidisciplinary design optimization incorporating aerodynamics, structure and stealth**

5. The evolution of the fighter planes

- **Limitations of current stealth fighters**
  - **Too expensive to be deployed in a large number (F-22 costs $13M for each!)**
  - **Stealth performance is not so good above the aircraft as beneath aircraft**
  - **When launching the weapons, the door is open and aircraft is able to be detected**
  - **Narrow internal weapon bay limits the count and type of payload**
  - **Stealth coatings are expensive to maintain. Its effectiveness is affected by weather or humidity**

5. The evolution of the fighter planes

2. Ground Attack planes – An embarrassing member in the air force fleet

A-10

Su-25

5. The evolution of the fighter planes

2. Ground Attack airplanes – An embarrassing member in the air force fleet

- Will ground attack be replaced by attack helicopters or fighter bombers?

A-12

AH-64

F/A-18 E/F

5. The evolution of the fighter planes

2. Ground Attack planes – An embarrassing member in the air force fleet

- **Pros:**
  - **Heavily armored. Can survive from harsh combat environment**
  - **Heavily loaded. Can carry large amount of weapon with wide variety**
  - **Superb maneuverability at low altitude and low speed**
  - **Relatively cheap and cost effective. No complicated and expensive avionics**
  - **Much faster than helicopters**
  - **Very suitable for low value tactical targets**

5. The evolution of the fighter planes

2. Ground Attack planes – An embarrassing member in the air force fleet

- **Cons:**
  - **Vulnerable when under attack by fighter aircraft.**
  - **Many of its missions can be accomplished by fighter bombers**
  - **It is more cost effective to derive a fighter bomber from a fighter than develop an attack aircraft**
  - **Much shorter battle radius compared to fighter bomber**
  - **Avionics is too simple**
  - **Compared to attack helicopters, it still needs airport**

5. The evolution of the fighter planes

3. Fighter bombers

F-15E

FBC-1

5. The evolution of the fighter planes

3. Fighter bombers

- **Features:**
  - Possessing at least partial fighter capabilities
  - Some of them are derived from fighters, thus significantly reduces the R&D cost
  - Usually much faster than attack aircraft
  - Equipped with advanced avionics
  - Almost equivalent maneuverability of fighters

5. The evolution of the fighter planes

4. UAVs --- The master of the future sky

5. The evolution of the fighter planes

4. UAVs --- The master of the future sky

- During the Korean war, U.S army deployed some UAVs
- During the Vietnam war, over 2500 U.S aircrafts are shot down and 5000 aircrew are dead. U.S deployed a lot of UAVs, such as AQM-34 “Firebee”

5. The evolution of the fighter planes

4. UAVs --- The master of the future sky

- UAVs primarily performs reconnaissance missions
- Now UAVs also carries AAM and AGM to perform target detection and attack mission simultaneously

5. The evolution of the fighter planes

4. UAVs --- The master of the future sky

- **UCAVs**

5. The evolution of the fighter planes

- Features of UCAVs
  - Secure and efficient remote data link
  - Fully autonomous based on artificial intelligence and sensor fusion technologies
  - No human, no cockpit
    - High lift to drag ratio
    - High maneuverability
    - Low RCS
    - No KIAs

6. Modern avionics and weapon systems

1. Airborne target detection system

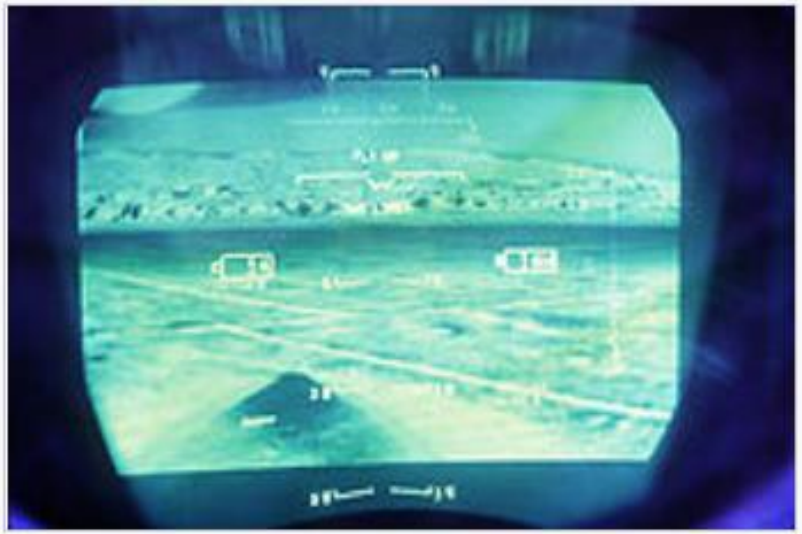
- **IR sensors (FLIR)**
  - Detects infrared signal and convert it into image
  - Detects targets passively. Impossible for enemy to detect
  - Can detect “heat”, which is very hard to camouflage
  - Can detect objects whose temperature is 0.2° C different from the environment
  - Can see through smoke, fog etc.

6. Modern avionics and weapon systems

1. Airborne target acquiring system

- **Application of IR sensors (FLIR)**
  - **LANTIRN**

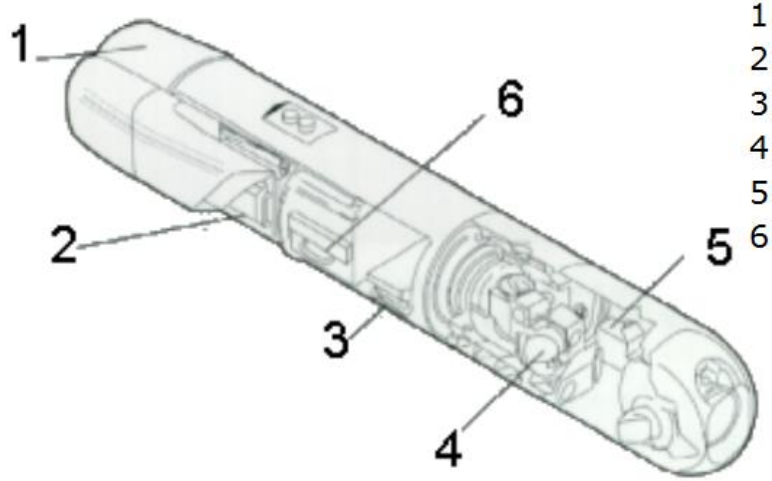
AN/AAQ-13 LANTIRN navigation pod aboard an F-15E



F-15E Heads-up display of infrared image from the AN/AAQ-13 LANTIRN navigation pod

6. Modern avionics and weapon systems

1. **Airborne target acquiring system**
- **Application of IR sensors (FLIR)**
  - **LANTIRN**



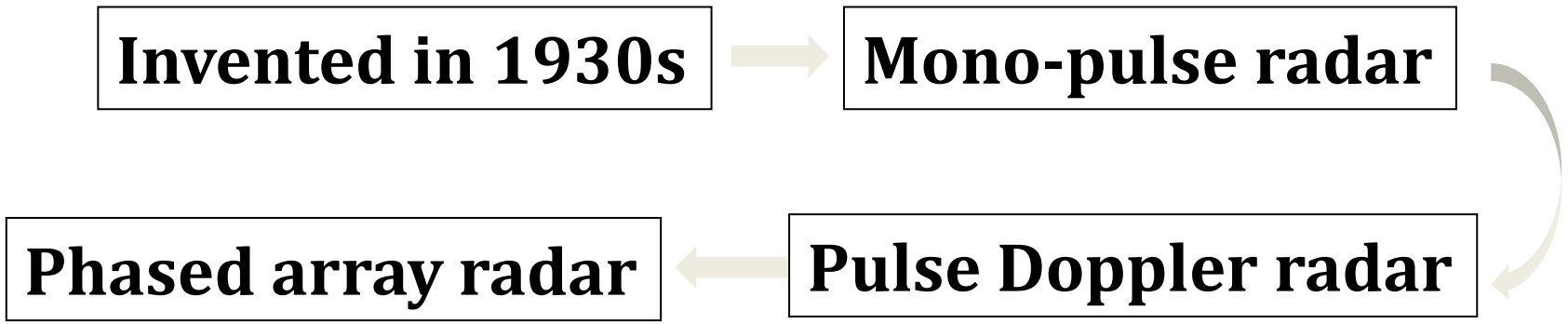
1. Environmental Control Unit
2. Power Supply
3. Control Computer
4. Forward-Looking Infra-Red
5. Laser
6. Missile Boresight Correlator

AN/AAQ-14 Targeting Pod

6. Modern avionics and weapon systems

1. Airborne target acquiring system

- **Radar**



6. Modern avionics and weapon systems

Airborne target acquiring system

- **Phased array radar**
  - **Active electrically scanned array (AESA)**
    - **Composed of numerous small solid-state transmit/receive modules (TRMs)**
    - **Transmit radio waves across a band of frequencies to remaining stealthy**
  - **Passive electrically scanned array(PESA)**
    - **Has only one central radio frequency source and one receiver**
    - **Inferior to AESA on band width, sign procession. But superior to mechanically scanned array**

6. Modern avionics and weapon systems

- **Radar**

– **Active phased array radar**

- **Can keep working even 10% of modules are damaged**
- **Electronic scanning is much faster and more efficient than mechanical scanning**
- **Detect, track, indentify and guide a lot of targets simultaneously**
- **Can be integrated with more functions such as electrical warfare, ultra high bandwidth communications**

6. Modern avionics and weapon systems

- **Cockpit and helmet systems**
  - **Early cockpit is full of instruments and switches**

6. Modern avionics and weapon systems

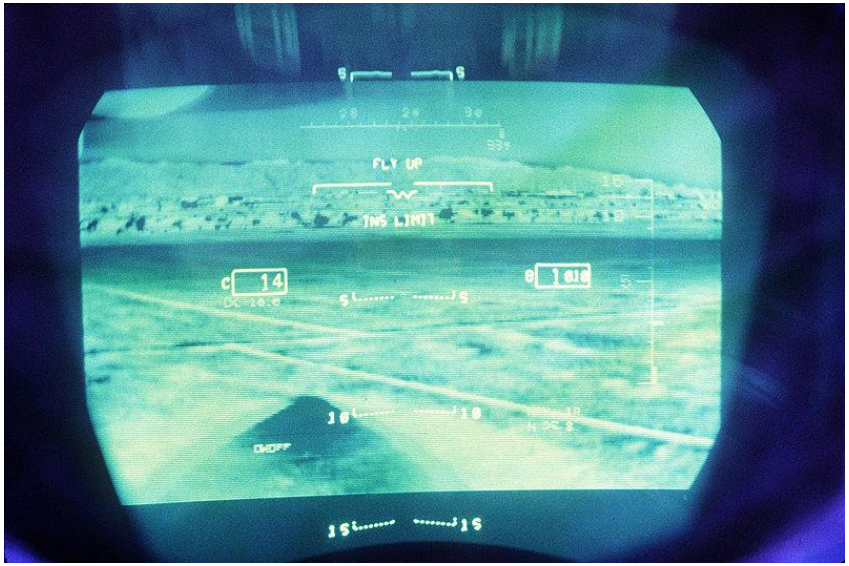
- **Cockpit and helmet systems**
  - **Some of them equipped with CRT to work as a navigation or radar screen**

6. Modern avionics and weapon systems

- **Cockpit and helmet systems**
  - **In the late 1970's, MFD appears in the cockpit of F-18 Hornet**

6. Modern avionics and weapon systems

- **Cockpit and helmet systems**
  - **Wide angle HUDs that can mix FLIR image with characters appears in the cockpit of F-15/F-16**



6. Modern avionics and weapon systems

- **Cockpit and helmet systems**
  - **Now in the F-35 cockpit, HMD replaced HUD**

6. Modern avionics and weapon systems

- **Weapons**

  5th generation Infrared guided AAMs

- **Low drag configuration designed for high maneuverability**
- **Equipped with imaging infrared (IIR) to distinguish aircraft from infrared countermeasures (IRCM) such as flares (Focal plane has 128X128 sensors)**
- **Can synchronize with HMD to attack targets within front hemisphere of aircraft**
- **Greater sensitivity means longer range or the ability to identify UAV**

6. Modern avionics and weapon systems

Weapons

5th generation Infrared guided AAM

AIM-9X

ASRAAM

Python-5

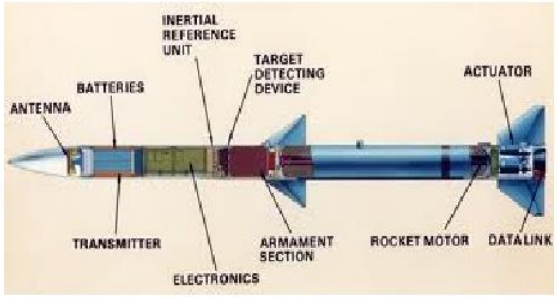
6. Modern avionics and weapon systems

- **Weapons**

  4th Generation radar guided AAM

- **Long range (50km~80km)**
- **Attack multiple targets simultaneously**
- **Fire and forget improves survivability of aircraft**

SD-10



AIM-120

AA-12

6. Modern avionics and weapon systems

- **Weapons**

  AGM

  – **Radar, Laser, GPS, INS, TV/IR guided**

  – **Trend of modern AGMs:**

    - **Long range, stand off**
    - **Apply stealth coatings and higher speed to penetrate enemy defense**
    - **High precision**
      More powerful war head to destroy targets at one attack
    - **Cluster war head to destroy targets at once**

6. Modern avionics and weapon systems

- **Weapons**

  Modern guided bombs

  - **High precision attack**
  - **Much more powerful than AGMs**
  - **Longer range than traditional bombs**
  - **More simple and cheaper than AGMs**
  - **Usually needs only one guided bomb to destroy targets. Very cost effective**
  - **More flexible. Can attack various types of targets**

6. Modern avionics and weapon systems

- **Weapons**

  Modern guided bombs

  – **Laser guided Bombs**

6. Modern avionics and weapon systems

- **Weapons**

  Modern guided bombs

  – **GPS/INS guided Bombs**

LS-6

6. Modern avionics and weapon systems

- **Weapons**
  - **Cluster Bombs**

CBU-105 Sensor fused weapon

Skeet war heads BLU-108