Introduction to Subsystems Testing

412 TW

"Warriors Committed to Readiness and Quality Support"

15th Annual ITEA Test Instrumentation Workshop

May 9th, 2011

Thane Lundberg
Technical Expert
Subsystems Integration Flight
773rd Test Squadron/ENFM
Edwards AFB, CA 93524
thane.lundberg@us.af.mil

U.S. AIR FORCE

Approved for public release; Distribution is unlimited
AFFTC-PA-10215

Biography

412 TW

Mr. Lundberg is a 1986 graduate of San Diego State University and is the Technical Expert for the Subsystems Integration Flight of the 773rd Test Squadron, 412th Test Wing, Air Force Flight Test Center, Edwards AFB, California. He is the Vice Chair for the AIAA Flight Test Technical Committee and has 12 years experience as a flight test engineer at Edwards AFB and 13 years experience as a US Navy depot level maintenance engineer at North Island, California, and Atsugi, Japan.

Mr. Lundberg was awarded the Meritorious Civilian Service medal and has provided engineering support for the testing or maintenance of 75 different model/design/series aircraft.

A-4E A-6E A/V-8B
B-1B B-2A B-52H
C-2A C-5A/B/M C-17A C-32A C-130E/H/J CV-22A
CompAir-7SLX
E-2C E-8C EA-6B EP-3E ES-3A
Euro Hawk
F-14A/B/D F-15SG F-16C F/A-18A/B/C/D F-22A F-35A
Global Flyer Global Observer
KA-6D KC-130L/R/T KC-135E/R
LC-130R
MQ-1
OV-10D
P-3B/C
RQ-4A/B
S-3B
T-1A TA-4E T-6A T-38A/C
UP-3B US-3A U-2S
YAL-1
X-37A/B X-47B
AH-1W
CH-46E CH-53D/E HH-46D
SH-2F/G SH-3G/H SH-60B/F
UH-1N UH-3H

Purpose

Provide an introduction into subsystems ground and flight test concepts and procedures for manned and unmanned aircraft.

An introduction to subsystem components is included to establish a basic system level understanding.

After taking this course the student will be familiar with the fundamentals required for performing the duties of a Subsystems Flight Test Engineer.

Tutorial Overview

412 TW

- **Subsystem Testing Overview**

- **Test Phases**
  - **Design**
  - **Qualification**
  - **Ground**
  - **Taxi**
  - **Flight**
  - **Follow On**

Tutorial Overview

412 TW

- Covered Subsystem Disciplines
  – Landing Gear/Brakes/Anti-skid
  – Arresting Gear
  – Fuel
  – Aerial Refueling
  – Hydraulics
  – Environmental Control
  – Climatic Laboratory
  – All Weather

Tutorial Overview

412 TW

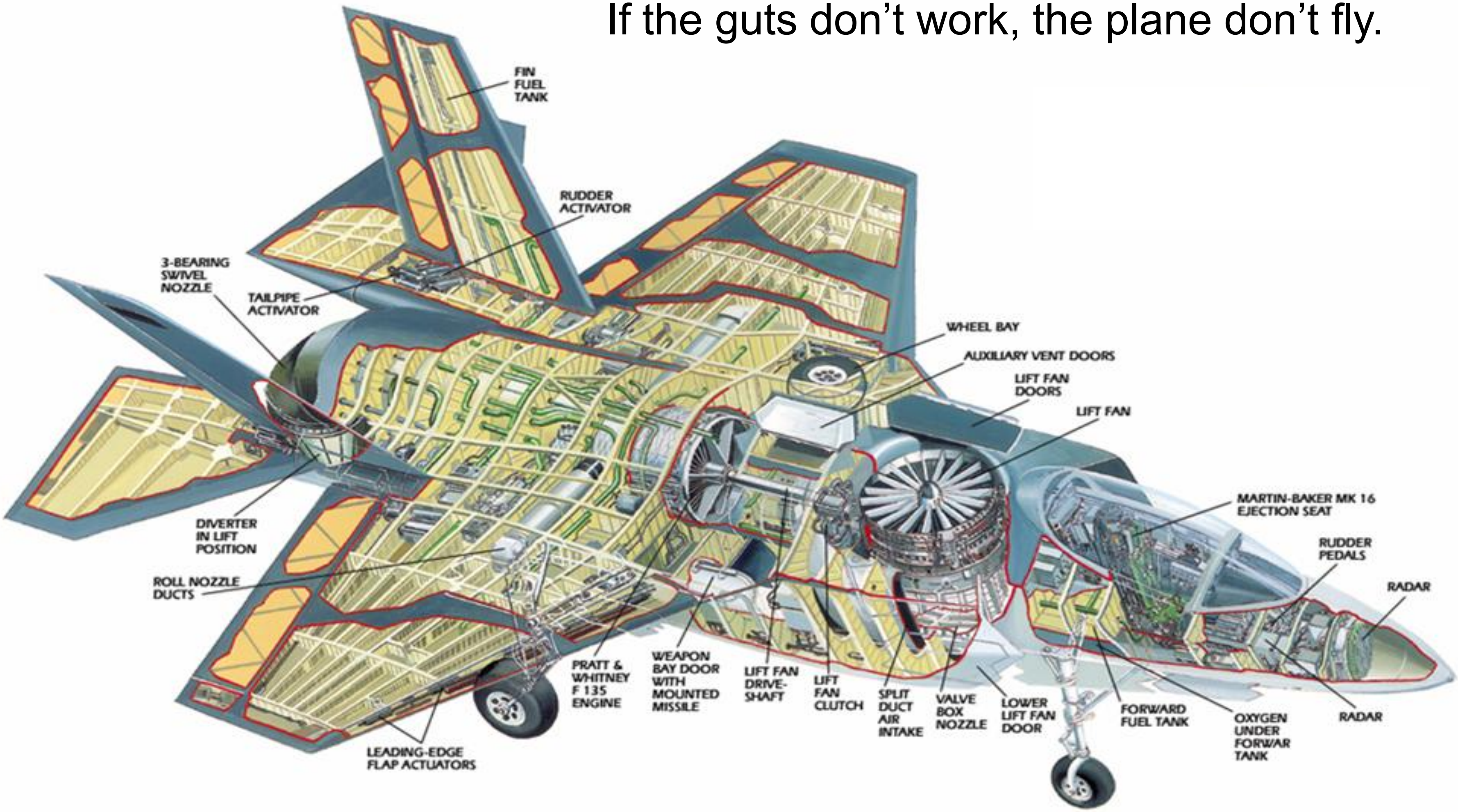
- 4 Hours is not enough time to cover all disciplines

- Omitted Subsystem Disciplines
  - Electrical Power Generation and Distribution
  - Fire Detection
  - Fire Suppression
  - Nitrogen Generation and Distribution
  - Oxygen Generation and Distribution

Subsystems Testing Overview

412 TW

Beauty is more than skin deep.
If the guts don't work, the plane don't fly.



Subsystems Testing Overview

- **Common military and civilian aircraft subsystem disciplines include:**
  - **Climatic and All Weather**
  - **Electrical Power Generation and Distribution**
  - **Environmental Control**
  - **Fire Detection**
  - **Fire Suppression**
  - **Fuel**
  - **Hydraulics**
  - **Landing Gear/Brakes/Anti-skid**
  - **Oxygen Generation and Distribution**

Subsystems Testing Overview

412 TW

- **Military unique aircraft subsystem disciplines include:**
  - **Aerial Refueling**
  - **Arresting Gear**
  - **Nitrogen Generation and Distribution**
    - Changing with evolving FAA requirements

Subsystems Testing Overview

- **Subsystems interface with all aircraft systems**
  - **Need to provide proper information, protection, power, air and fuel to:**
    - Avionics
    - Flight Controls
    - Aircraft Health Management
    - Pilot, Crew and Passengers
    - Propulsion
    - Weapons
- **Subsystems are getting more interdependent**
  - **e.g. a computer controlled ECS that cools avionics, crew and hydraulics while using fuel as a heat dump**
    - What happens when the fuel gets too hot?

Subsystems Testing Overview

- **Subsystems testing is evolving into an avionics based test philosophy**
  - **Subsystems are becoming more automated**
    - The pilot votes; the computers allow, execute and control
      - Integrated Vehicle Subsystem Controller (IVSC)
      - Vehicle Management System (VMS)
      - ECS, Fuel, Hydraulics and Electrical Power System Controllers
  - **The controllers use sensors to detect conditions and issue commands to achieve results**
    - This requires insight into input and output from each component
      - Sensor to data distribution point to controller to effectors to result to feedback

Subsystems Testing Overview

- **Subsystems testing is special**
  - **Every engine start is a test point**
  - **Every taxi out is a readiness for flight check out**
  - **Every flight is in a new aircraft configuration due to part changes and component wear**
  - **We can’t prove it will work next flight**
    - Just because it worked today doesn’t mean it will work tomorrow
    - Because it worked today may increase the probability it won’t work tomorrow
  - **Every weather and flight condition is an opportunity for an unexpected event or deficiency to occur**

Subsystems Testing Overview

- **Subsystems testing is fun**
  - **Not a lot of obscure equations**
  - **Not a lot of coefficients derived from difficult to measure phenomena**
  - **Most measurands are easy to comprehend but may be difficult to measure**
    - Pressure
    - Temperature
    - Flow rate
    - Voltage/Current
  - **Lots of interesting tests with real world application**
    - Does the landing gear retract and extend?
    - Does the aircraft stop safely?
    - Does the aircraft bleed, leak, spark, smoke or smell bad?

Subsystems Testing Overview

- We look at data from before engine start to after engine shutdown
  - Performance on ground electrical, hydraulic and bleed air power
  - System transients and performance as APU and engines are started
  - Taxi out and preparation for takeoff
  - Throughout the flight, whether doing a test point or not
  - Landing and taxi back
  - System transients during shut down
- We expect different performance today than yesterday

Subsystems Testing Overview

- **We usually test to a defined specification**
  - **When the specification is wrong, we try to change it before the test plan is written**
  - **It usually doesn't matter by how much you 'beat' the specification**
    - Actual 115.0 ± 0.1 volts may be just as good as specification required 113.0 to 117.0 volts

- **We Use All Possible Data in Our Evaluation**
  - **Test reports include planned test points and data from all possible ground and flight events**
    - e.g. a dry runway landing gear performance report included data from144 test points and an additional 1,280 braking events

Subsystems Testing Overview

412 TW

- Statistical techniques considered for each test effort
  - We love to repeat test points, but…
- Stressor conditions and safety build ups can quickly use up a lot of the planned test points
  - If the number of test points are limited, we usually prefer looking at different stressor conditions rather than repeating test conditions
  - The system may have an unknown stressor, that’s why we always watch the data

Subsystems Testing Overview

412 TW

- **Subsystem engineers protect the aircraft and crew**
  - **Even with no subsystem test points planned, subsystem engineers are usually in the control room or sitting near the phone**
    - Murphy’s Law was developed at Edwards AFB and is rigorously complied with

- **Should see problems developing, quickly separate the truth from the noise, and advise the test team and pilot before an adverse event occurs**

Subsystems Testing Overview

- When the Master Caution Light illuminates all eyes usually turn to the subsystem engineer
  - What happened?
  - What will happen next?
  - What should we do?

- After landing they ask
  - Can we fly tomorrow?

Subsystems Testing Overview

- **A perfect test is usually not possible**
  - There are too many unknowns, potential weaknesses, and complex inter-relationships between subcomponents to allow for all conditions, or even perhaps the most critical condition, to be known or tested

- **We know something bad will happen to someone, someplace; regardless of what we do**
  - Service use will differ from that expected
  - System response due to wear and failures can't be fully anticipated

Subsystem Testing Overview

- **We don’t want an unsuspecting fleet pilot become a unknowing test pilot**
  - **We want to test every new component**

Subsystems Testing Overview

- The following AFFTC Handbooks are on your CD
  - Aircraft Arresting Gear Testing
  - Aircraft Brake System Testing Handbook
  - Aircraft Brake System Testing Handbook Addendum
  - All-Weather Testing
  - Electrical Subsystems Flight Test Handbook
  - Engine Inlet/Nose Tire Water Ingestion
  - Environmental Control Subsystem
  - Flight Testing Under Extreme Climatic Conditions
  - Fuel Subsystems Flight Test Handbook
  - Landing Gear Subsystem Testing
  - Hydraulic Subsystem Flight Test Handbook
  - Natural and Artificial Icing/Rain Testing

Subsystems Testing Overview

- **AGARD-AG-300 Volume 14, Introduction to Flight Test Engineering, is on your CD**
  - Sections 1 and 2 provide insight into the question of why flight test and give a short history of flight test engineering
  - Sections 3 through 10 deal with flight test preparation
  - Sections 11 through 27 describe the various types of flight tests that are usually conducted during the development and certification of a new or modified aircraft
- **Accuracy or relevance of the information has not been verified by the AFFTC**
  - That should keep me out of trouble

Subsystems Test Phases

412 TW

- Design Phase
  - Must understand and can influence the system design
- Qualification Tests
  - Can it endure the specified environment
- Ground Tests
  - Is it ready for flight
- Flight Tests
  - Test the strengths and weaknesses of the system
- Climatic Lab Tests
  - Is it deployable
- All Weather Tests
  - Can it execute the mission under real world conditions
- Follow On Tests
  - Use flight test corporate knowledge to improve test conduct

Design Phase

- **Modern test teams are integrated into the development process**
  - **Our first chance to see the design and provide comment**
    - We may have experience with previous successful concepts

- **If possible participate in Preliminary and Critical Design Reviews**
    - Need to protect proprietary information

Design Phase

- **Time to start test process by:**
  - **Influencing final design for usability and operability**
  - **Learning system requirements, strengths and weaknesses**
  - **Establishing contacts and building a team mentality**
  - **Developing the overall test concept**

Qualification Tests Caveats

412 TW

- **Qualification tests are good build ups, but are not a replacement for flight test**
  - **The flight environment is different from the lab environment**
    - The test spectrum will not match the flight spectrum
  - **The pre-flight lab test components may differ from the production components**
  - **The installation and maintenance of lab and flight line equipment is different**

- **Every smoking hole is filled with equipment that passed every qualification test**

Qualification Tests

- Component level qualification tests
  - Shake and bake, freeze, thaw, heat, salt bath, chemical, and almost everything else you can imagine
- Software Integration
  - Avionics lab and cockpit simulator
- Computer-based system modeling and simulations
  - Be aware of fidelity and configuration control

Qualification Tests

412 TW

- The Iron Bird
  - Optimally a full scale replica of all subsystems
    - With a good representation of line, hose, duct and major component layout
    - May not have a full up fuel system; no skin to define tanks
  - Can be used to determine and verify flow, pressure, thermal and electrical characteristics
    - Should correlate with computer models
  - Generally integrated with avionics and flight control system
    - Can control flight surfaces and other components
    - May be used to troubleshoot flight test anomalies

Qualification Tests

- **Electrical System Simulator**
  - **Full up reproduction of electrical system**
    - Generators, Power Control Units, buses, electronic breakers, wiring, and most boxes
    - Normal and failure modes should be fully evaluated
  - **A lot of ‘real’ testing goes on here**
    - Flight test may be a graduation exercise for many functions
    - Difficult to plan and execute failure mode flight tests
      - Not a popular test regime, may disable some redundancy

Ground Tests

Ground Test Overview

- **Demonstrate the aircraft is ready for flight**
  - **Not all system functions can be tested**
  - **Many tests do not use a control room**
    - May use workstations, laptops or eyeballs

- **Participate in as many tests as possible**
  - **Rehearsal for taxi and flight**
  - **Verify instrumentation and data reduction process**
  - **Control room checkout**
    - Learn how to use equipment and modify displays
    - Learn other disciplines screens

Typical Ground Tests

412 TW

- **Subsystem performance on ground, APU and engine power**
  - **Electrical**
    - Power transfers
    - Avionics operations
    - EMI/EMC
  - **ECS**
    - Heat and cooling under all power modes
  - **Fire Detection and suppression**
    - Detector loop checks
    - Use HFC-125 instead of Halon 1301 for agent release
  - **Fuel**
    - Fuel quantity calculations and transfer
  - **Hydraulics**
    - Flight control and weapon door actuation

Taxi Tests

412 TW

Taxi Test Overview

412 TW

- **Last step before flight**
  - **Rehearsal for first flight**
- **Typical brake test technique is full brake pedal application with 1 second ramp rate**
  - **On dry, wet and icy runways**
  - **Try that on the ride home**
- **Axle grease and hydraulic fluid fire possible or probable**
  - **Person at greatest risk is usually ground crew and fire department**

Taxi Test Overview

- **Fuse plug release (flat tires) likely**
  - **Will shutdown the runway**
- **Dry runway before wet runway**
  - **Dry is no water on runway**
- **Wet runway before icy runway**
  - **Wet runway may follow first flight by months or years**
  - **Wet should be defined**
    - Wet taxi test cannot be done on a grooved surface
      - Friction is too high to be relevant to un-grooved operations
  - **Icy runway during all weather testing**
    - Deicing trucks with spray nozzles and water make good ice

Taxi Test Overview

412 TW

- For the AFFTC wet is ≤ RCR 17
  - RCR Runway Condition Report is Mu measured by a Mu-Meter times 32.2
  - Mu measured by other friction measuring systems is not the same
  - Mu measured by a friction measuring system is not the same Mu experienced by the aircraft
- Wet surface must result in an anti-skid response but not so wet that the tire hydroplanes

Taxi Test Overview

- **May test on more than one surface**
  - **Conventional runway – concrete, asphalt, battle damage repaired**
  - **Semi-prepared, unpaved runways**
    - Lakebed, gravel, dirt, mud, grass, ice, snow, matted runway

- **Good rules of thumb for deceleration performance**
  - **10 to 12 ft/sec^2 on a dry runway**
  - **6 ft/sec^2 on a wet runway**

Flight Test

Flight Test Overview

- **Subsystem test points are often "piggy back" or "ride along" with other disciplines**
  - **For example, performance and flying qualities high alpha test points are great for ECS, fuel and hydraulics testing**
  - **Let some other discipline pay for the test point**
  - **Make sure you keep track of changes in the parent test plan**

- **Make sure you're ready for back up test points**
  - **Back up test cards may be briefed for weeks**
    - Make sure all is ready to test
      - Aircraft stores, configuration, instrumentation and you

Flight Test Overview

- **Most flight test points are classical stressor conditions for the system under test**
  - **New stressors appear with every new design**
  - **Weak points are fair game**
- **The AFFTC Handbooks on your CD provide a very good overview of standard test concepts and methodology**
  - **If you had read those, you wouldn't be here**
  - **There will be a test tomorrow**

Flight Test Overview

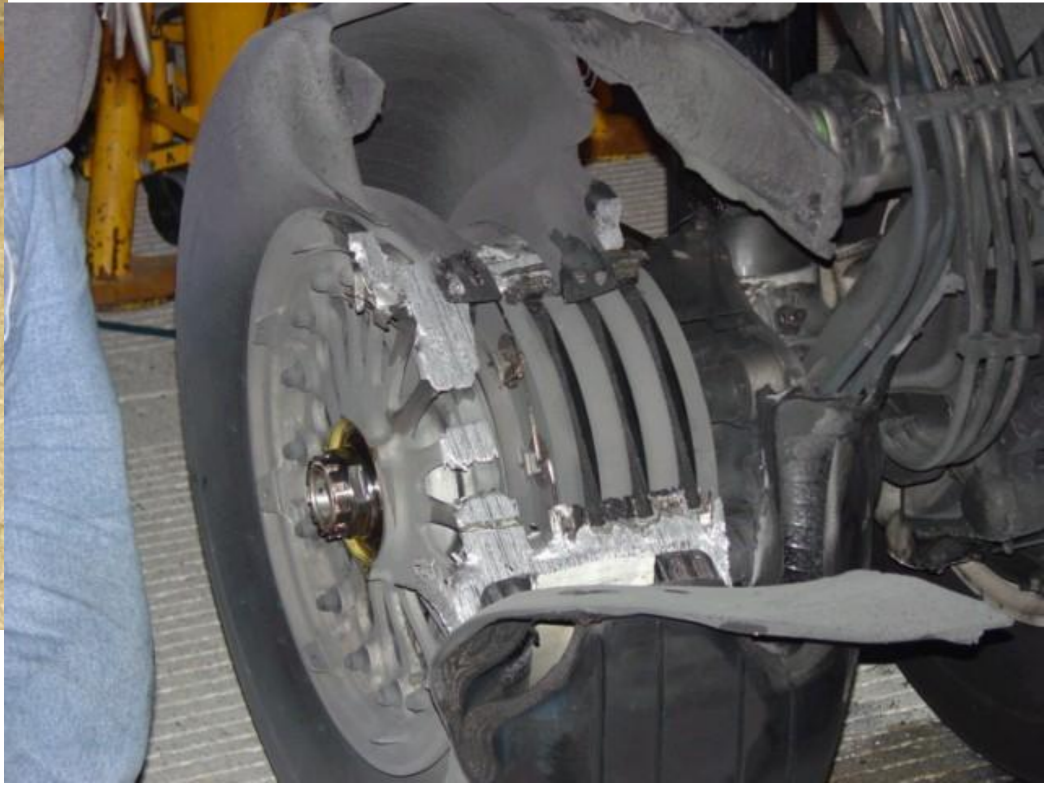
412 TW

- **All data on all flights can be used to evaluate performance**
  - **Failures usually have indicators before the event**
  - **The indicators may be difficult to see**
  - **Hindsight is 20/20**

- **Failures and emergencies are fair game for data**
  - **It is unethical and time consuming to cause them, so watch your screen**
  - **Think one to two failures ahead**
  - **Call "data on" when things go wrong**
    - Wait until the situation has stabilized

Follow On Tests Overview

412 TW



Follow On Tests Overview

- **Testing of new or improved components**
  - **Avionics, subsystems, materials and technology are always improving**
    - What you have is obsolete
    - Reliability and manufacturing updates are common
    - May be a new pump, controller, control box, sensor, etc.
    - Need to demonstrate no adverse or unexpected system response)
- **Aircraft weight always increase**
  - **New brake tests are common**
  - **New arresting gear tests are less common**
    - Unless loads or dynamics force a redesign or a new arresting system is fielded

Follow On Tests Overview

412 TW

- **The post production maintenance check may not be adequate**
  - **"Push a button, look for a light" just proves the bulb is not burned out**

- **Be wary of not testing if there is any impact to safe flight operations**

- **Hard to justify not taxi testing all brake related changes**

Follow On Tests Overview

- **Lots of regression testing with new or modified equipment**

- **Remember that the new component may not go through the same test regimes as the old component**
  - **High Alpha**
  - **Stressor Conditions**
  - **Climatic Lab**
  - **All Weather**

Follow On Tests Overview

- **Previous test plans and technical reports are an excellent source of data**
  - **May be difficult to repeat a previous test point and provide direct comparison data**

- **Assume the old deficiencies are not fully corrected and new anomalies will occur**

- **Be aware of unintended consequences**
  - **There is just so much power and cooling air available**
    - Changing flow in one branch can change flow in others

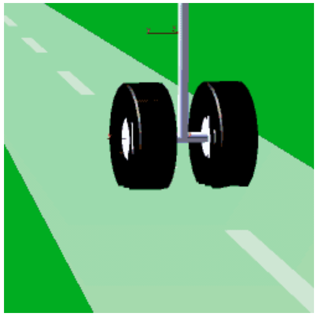
Landing Gear

412 TW

Landing Gear Overview

- **Provide means for taxi, launch and recovery**
  - **Supports the aircraft while it is on the ground**

- **Typical components include:**
  - **Struts to absorb landing shock**
    - Taxi shock absorbed by tires and perhaps struts
  - **Actuators for retract/extend and uplock/downlock**
    - Emergency extension system
  - **Sensors to detect gear position and WOW**
  - **Brakes and wheel speed sensors**
  - **Nose wheel steering devices**
    - May also be a shimmy damper and centering device
      - Shimmy is a lateral-torsional instability
      - Centering device ensures NLG wheel is aligned for retraction



Landing Gear Overview

412 TW

- **Aircraft kinetic energy is very high and most is absorbed by brakes**
  - **Ford Explorer ~ 4,400 lbs @ 82 mph (Verified by CHP) = 1.3 Million Ft-Lbs**
    - Equivalent to lifting an Explorer 295 feet
  - **C-17A ~ 585,000 lbs @ 130 KGS = 471 Million Ft Lbs**
    - Equivalent to lifting an Explorer 107,045 feet or ~ 20 miles

Landing Gear Overview

- **Knowledge of brake and tire characteristics is crucial to safe and cost effective test execution**
  - **Brake and tire temperatures are critical**
    - Person most at risk, the ground crew, may not be aware of the threat

- **Safe test execution relies on more than just the fuse plugs**

Landing Gear Overview

- **Hot Brake Operating Instruction**
  - **Describes how to safely execute repeated taxi tests without undue risk**
  - **Brake temps can exceed 2,000 degrees F**
    - All brake temps are not equal, each component has a unique temp
  - **Tire is unsafe at sidewall temps above 220 to 400 degrees F**
  - **Heat build up due to braking a concern for tests**
  - **NWS should be used during taxi out and back to minimize heat build up due to differential braking**

Landing Gear Qualification Tests

- **Anti-skid Control System**
  - **Including hardware and software**
  - **Hardware in-the-loop simulator**
    - Dry, wet and transitions
    - Ice, differential braking, dissimilar tires (new, worn and blown)
  - **Be aware of fidelity and configuration control**
    - Very difficult (impossible?) to model ground environment
      - Varying runway friction
      - Varying normal load
      - Tire and brake heating effects
    - Wheel speed is difficult to model
      - The model predicts the wheel speed, which is a measurement of anti-skid performance, and feeds this back into the model

Landing Gear Qualification Tests

412 TW

- **Brake dynamometer qualification tests**
  - **Large steel drum rotated at appropriate speed**
    - Wheel/brake assembly lowered onto wheel and brakes applied
  - **Good for brake energy and temperature evaluations**
    - Not as good as taxi tests for anti-skid evaluations
  - **Normal stop – fuse plug release margin**
    - Component and fluid temperature profiles
    - No damage allowed
  - **Refused takeoff (RTO) 100% brake energy**
    - Fuse plugs should release, piston seal should not leak, no fire for most military aircraft
    - Allowable damage to axle and brake in air vehicle specification

Landing Gear Qualification Tests

- **Brake Energy**
  - **92.3 Mft-lbs**
- **Brake Application Speed**
  - **175 knots**
- **Stopping Distance**
  - **3675 feet**
- **Average Deceleration Rate**
  - **11.9 ft/sec^2**

Courtesy of Honeywell-Dunlop Alliance

Landing Gear Qualification Tests

- **Aircraft don't normally land on large rotating steel drums**
  - **Unrealistic vertical force, maybe no-anti skid and no differential brakes**
  - **The mounting structure has different frequency and damping effects than aircraft structure**
    - Landing gear exhibit non-linear characteristics such as friction and damping that are dependent on the level of excitation
  - **The curved surface affects tire rolling dynamics such as cornering power, relaxation length, and tire lateral spring rate**
  - **Lab testing usually involves gear in new condition**
    - May not be typical of fleet installations

Landing Gear Ground Tests

- **NWS**
  - Static steering performance
  - Pedal and tiller response

- **Brakes**
  - Parking brake
  - Pedal forces and independence
  - Piston release
  - Primary and secondary/emergency hydraulics

- **Anti-skid**
  - Hubcap spin check, BIT, instrumentation checkout

Landing Gear Ground Tests

- **Aircraft on jacks**
  - **Gear swings and clearance checks**
    - Both normal and emergency systems with resets
  - **Anti-skid**
    - Touchdown protection – No brakes with pedals applied
    - WOW switch back up – Brakes available with hubcap spin check
  - **WOW switch check**
    - Show transfer to ground mode
  - **Flight control movement presents hazard of falling off jacks**

Landing Gear
Taxi tests

412 TW

- **Braking and steering**
  - **Differential braking and NWS**
    - S turns using each and both
- **Brake temperatures should be predicted and monitored**
  - **The real threat is hot tires**
  - **AFFTC is working on a wireless brake and tire monitoring system**
    - Brake temps
    - Tire pressure and temps

Landing Gear
Taxi tests

412 TW

- **Low speed 0-20 knots**
  - **Brakes – light to moderate, differential**
  - **Steering – handling, turns, s-turns, heading drift**
  - **Usually anti-skid is not active**

- **Moderate Speed 20-80 knots**
  - **Brakes - max pedal, ramp and step input**
    - Brake temps match predictions
  - **Anti-skid, no lock-ups, transition below anti-skid protection (~20 knots)**
    - Evaluate stopping deceleration, distance and efficiencies
  - **Steering, handling and heading, low gain NWS transition, differential braking**
  - **Gear shimmy and gear walk stability**

Landing Gear
Taxi tests

412 TW

- **High Speed 80-160 knots**
  - **Same considerations as moderate speed**
  - **High brake energies and speeds increase risk**
  - **Typically below rotation speed**
  - **Aircraft must be capable of flight if test is near rotation speed**

Landing Gear Taxi tests

- High kinetic energy brake tests
  - Hydraulic and/or grease fires likely
  - Landing gear damage likely
- Refused Takeoff (Military)
  - Typical with fully worn brakes (no fire)
- Rejected Takeoff (FAA)
  - Mixed new and fully worn brakes (5 minute burn)
  - Tire pressure set cold to the highest value
  - EAFB is a great place to do this, ask Boeing

Landing Gear
Taxi tests

- **90% Maximum Brake Energy RTO Test**

Landing Gear
Taxi tests

- **Anti-skid optimization**
  - **Improve stopping efficiency and performance to meet specifications for landing and stopping distance**
  - **Landings light to heavy**
  - **RTO's medium to heavy**
  - **Wet runway**
    - Initial clearance, full matrix, hydroplaning, anti-skid efficiency, steering
  - **Lots of regression with each tuning iteration**
- **Emergency braking**
  - **Usually with a limited number of applications**

Miscellaneous Landing Gear Taxi Tests

412 TW

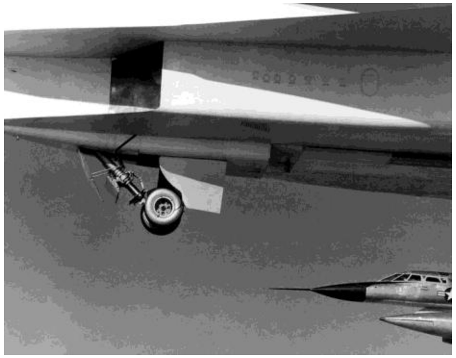
- Towing
  - Fwd/back, turns to the limits, steering and scissor links connected/disconnected, tow brakes
- Turns
  - Min radius, multi-point, high speed, tip over stability, 100% loads on gear, bump and dip
- Parking brake
  - Holding at power, after sitting on an incline (ambient temp drop)
- Backing and tip-back stability
- Engine inlet water spray

Landing Gear Flight Tests

- **Takeoff**
  - No instabilities or shimmy
  - Be ready for RTO on every mission
- **Wheel speeds decrease evenly before and during retraction**
  - Fast decel may indicate dragging or damaged brake
- **Verify gear doors are closed and show proper position**
- **Verify brakes are off**
  - Depress brake pedals and look for brake pressure

Landing Gear Flight Tests

- **Retraction**
  - **Gear and door articulation, sequencing and sensing**
  - **Tire de-spin**
    - May be brakes (MLG) or pads (NLG)
    - Reduces gyroscopic forces - tire profile
    - Max effort takeoff – Retract ASAP after takeoff
  - **Sensors show up and locked**
  - **Doors seal (chase verify)**
  - **Gear meet predicted retraction time**
  - **Verify landing gear hydraulics are isolated or brakes are off**
    - Depress brake pedals and look for brake pressure



Landing Gear Flight Tests

- **In Flight - Gear Up**
  - **Doors should remain closed**
    - Stealth and aero loading concerns
  - **Temps should be monitored or estimated**
    - May have gear up temp limits
    - Be ready to Return to Base (RTB)
      - Brake cool down rate higher with gear down
  - **Keep an eye on Hydraulics and Electrical Systems**
    - Think one or two failures ahead
    - Help out the other disciplines
      - If they are having a bad day, so are you

Landing Gear Flight Tests

- Extension
  - Gear and door articulation, sequencing and sensing
  - Gear down and locked (chase verify)
- Retract and extend up to limit speed
  - With varying sideslip, alpha, load factor (Nz)
- Landing Gear Reversal
  - Look for loads, proper brake and anti-skid status
- Emergency/alternate extensions
  - Should demonstrate reset feature if possible

Landing Gear Flight Tests

- **Landing and rollout**
  - **Touchdown protection**
    - Usually brakes and NWS are off at touchdown
  - **Weight on wheels**
  - **Good deceleration and steering, no skids or shimmy**
  - **Brake temps track predictions**
- **Taxi back**
  - **NWS and brake temps**
    - May indicate dragging brakes
- **Crosswind and high sink rate landings**
  - **Primarily a loads test**
  - **Check for gear stability**

Arresting Gear

412 TW

Arresting Gear Overview

- A series of components used to stop an aircraft by absorbing its momentum in a routine or emergency landing or aborted takeoff
- Typical requirements
  - Deploy
  - Engage
  - Decelerate
  - Release
  - Retract

- Arresting gear may be use as hold back fitting for engine runs

Arresting Gear Overview

- **Arresting gear is on the aircraft**
  - **Extension or release system**
  - **Hold down, snubber and centering device**
  - **Retraction system not always present**
    - Should be able to lift clear of cable after stop to taxi off runway

- **Arresting system is on the ground**
  - **Cable or Barrier**
  - **Purchase Tape**
  - **Energy absorber**
    - Chain, fabric, water drum, brakes
  - **Engaging device, sheaves, etc**

Arresting Gear Overview

412 TW

- **Emergency Arresting Gear and System**
  - **Limited number of engagements for aircraft components and structure (F-16)**
  - **Long system recycle time**
    - Chain or textile system

- **Operational Arresting Gear and System**
  - **Greater (but limited) number of engagements for aircraft components and structure (USN and F-22)**
    - Fly in engagement capability common USN requirement
  - **Short system recycle time**
    - Retract motor (BAK-12/-13)

Arresting Gear Overview

412 TW

- **Pendent (cable) type most common**
  - **Cable attached to purchase tape which is retarded by energy absorbers**
    - Typically rubber donuts keep cable at correct height
    - Pendant may be deployable (BAK-11/-14)
- **Chain barrier first to be deployed**
  - **Cable attached to anchor chain**
- **Net barrier catches aircraft**
  - **Aircraft is ensnared by net**
  - **Net is retarded by energy absorber**

Arresting Gear Overview

412 TW

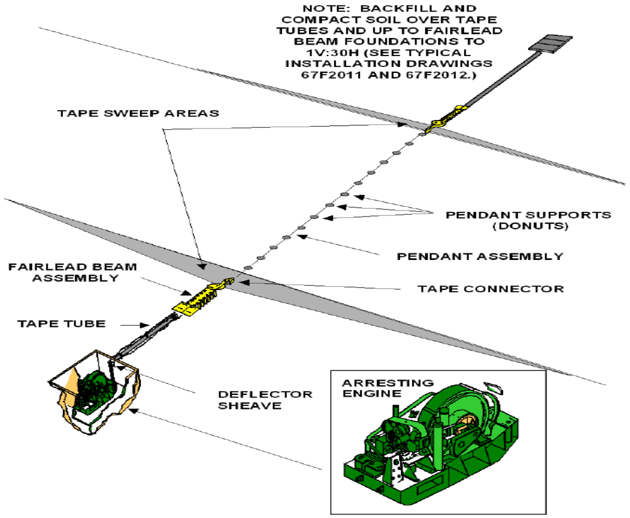
- **Gratuitous aircraft in a net pictures**

BAK-12 Arresting System

412 TW

- **Standard USAF arresting system**
- **Bi-directional system with an energy absorber on each side of runway**
  - Each absorber consists of 2 multi-disc rotary friction brakes
  - Self contained hydraulic system powered by rotating purchase tape spool

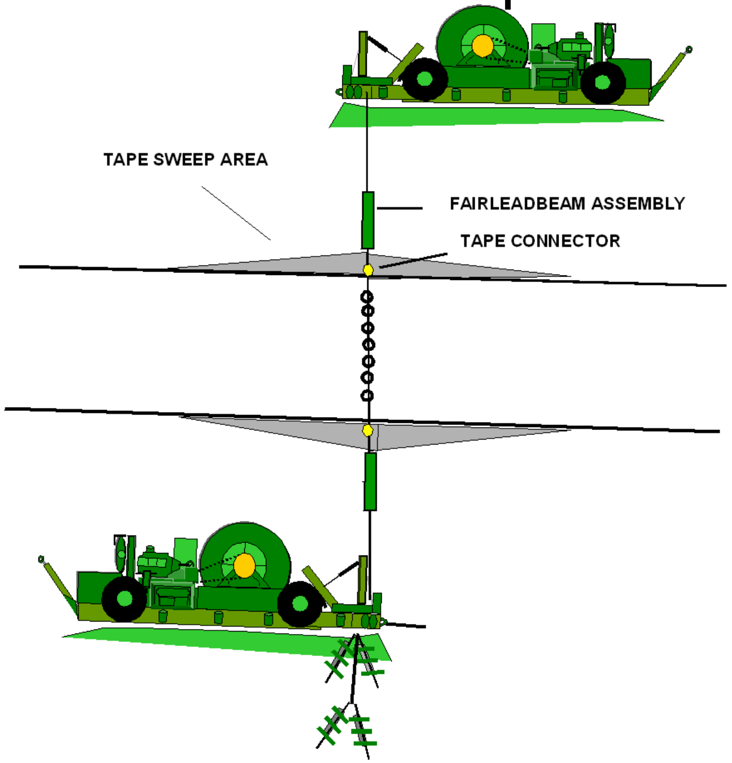
Figure A2.6. BAK-12 Aircraft Arresting System.



MAAS
Mobile Aircraft Arresting System

412 TW

- **Trailer mounted BAK-12**
- **Can be used to quickly install arresting system on runway midpoint**
  - Allows high speed engagement with hook skip recovery zone

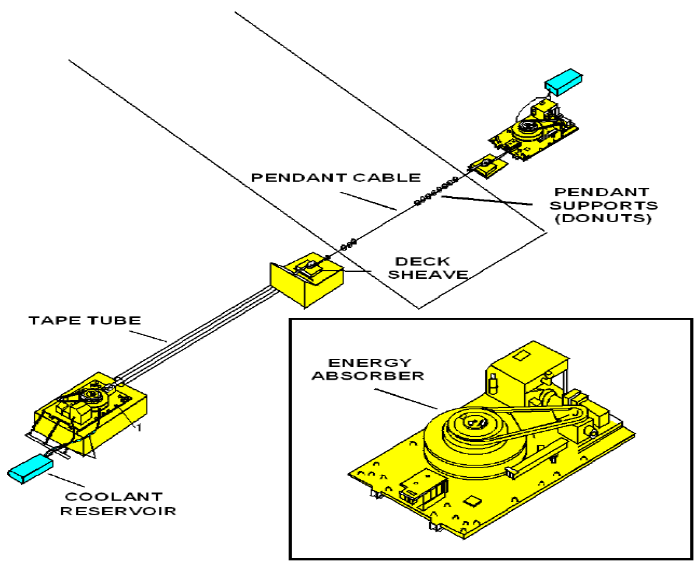


BAK-13 Arresting System

412 TW

- **Similar to standard USN E-28 arresting system**
- **Tape-storage reel on a vertical shaft with a vaned rotor and stator assembly that contains a water and glycol mixture.**
  - –The KE converted to heat via turbulence created by rotor
  - –Coolant reservoir permits repeated engagements

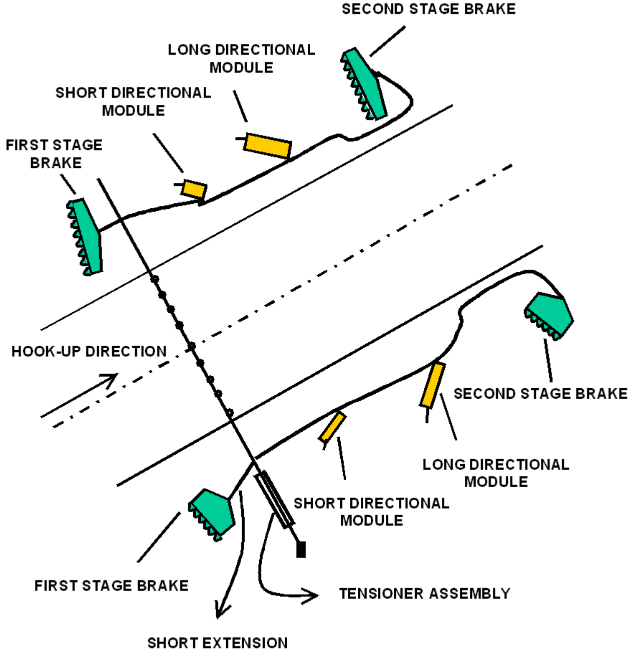
Figure A2.7. BAK-13 Aircraft Arresting System.



Textile Brake Arrestment System

412 TW

- **Usually an emergency back up system**
- **Textile tearing straps absorb the aircraft kinetic energy**
  - **Expended brakes are discarded**
  - **Unexpended brakes are moved to first stage brake**



Arresting Gear Ground Tests

- Static tests usually performed before first flight and repeated during dedicated arresting gear testing
  - Hook functional tests - extend, retract
  - Hold down force
  - Component and door clearances

Arresting Gear Taxi Tests

- Hook loads differ with each arresting system
  - BAK-13 has higher initial load
- Cable response differs with each runway span
  - May have cable slap damage to aircraft with 150 foot span and none with 300 foot span
- Which system do you test?
  - BAK-12 with 300 foot span most benign but 300 feet is not fleet representative
  - BAK-13 with 150 foot span may be worse case

Arresting Gear Taxi Test

- **Cable rollover tests may be performed on aircraft without arresting gear to determine maximum allowable crossing speed**

- **Cable bounce from rollover can impact flight controls, fuselage, doors, external stores or antennas**

Arresting Gear Taxi Tests

- **Monitor cable, hook and aircraft dynamics**
  - **Ground and aircraft video**
- **Monitor gear and fuselage loads**
  - **EAFB BAK-12 is not instrumented**
    - Brake pressure and tachometer on operators panel
    - Load cell between cable and purchase tape is possible
  - **NLG side loads desired for off-center engagements**
- **Monitor wear and free play**
  - **Fuselage could be critical area**

Arresting Gear Taxi Tests

412 TW

- **Monitor aircraft roll-back**
  - **No tip-back, proper hook disengagement and retraction**
  - **Keep in mind real-world aircraft may not have brakes and/or nose wheel steering**
    - That may be the reason for arrestment
    - Roll-back over 200 feet is possible
    - Engine thrust can be used to control roll-back but that is tricky
- **Monitor arresting system status**
  - **Resynchronize no less than every ten arrestments**
    - Rests the cams and valves
    - The BAKs do not communicate with each other

Arresting Gear Taxi Tests

- Can be executed as taxi tests if sufficient acceleration and hook skip stopping distance is available
  - Low and medium speed usually as a taxi test
  - High speed may be after a landing
  - Don't test towards departure end cable
- MAAS can be used to provide mid-field engagement
  - Increases acceleration distance
  - Location should provide adequate braking distance for hook skip or arresting gear/system failure

Arresting Gear Taxi Tests

412 TW

- **Assume hook skip in test planning**
  - **Must have adequate stopping distance beyond cable**
  - **Should have observers call bolter (no damage) or abort (aircraft damage possible)**

- **Takeoff should not be default for hook skip**
  - **Failure of cable/pendant connector or energy absorber may result in trailing cable**
    - Reduced deceleration may not be noticed by pilot
    - Trailing cable may have fouled hook
  - **Arresting gear failure may result in aircraft damage**
    - Structural damage
    - Hydraulic system damage

Arresting Gear Taxi Tests

- **Initial taxi tests evaluate hook and cable dynamics**
  - **Drag hook down the runway**
    - Look at bounce, damping and hold down force
      - May use reduced damper pressure to maximize bounce
    - Area on both sides of AGS has tighter surface requirements then rest of runway
    - May start with hook down or deploy in motion
  - **Roll over pendant (hook up)**
    - Look at cable dynamics
    - Height at hook position
    - Clearance of underbody and stores, etc
- **If all looks good, start barrier engagements**

Arresting Gear Taxi Tests

412 TW

- Centerline engagements before off-center engagements
  – On runway centerline, perpendicular to pendant

- Requires a build up in speed and weight
  – Heavy weight may require tanks and stores
  – Water in external tanks may be used for weight but must be isolated from fuel system

Arresting Gear
Off-Center Engagements

412 TW

- Off runway centerline, perpendicular to pendant
- Offset distance function of runway width
  - 35 and 50 feet offset for 200 foot wide runway
  - 50 and 75 feet offset for 300 foot wide runway (EAFB)
- More dynamic than centerline engagements
  - Asymmetric loads on aircraft,
  - Increased pitch and yaw
  - High nose landing gear side and vertical loads

Arresting Gear Off-Center Engagements

412 TW

- May require a different build up
  - May start at medium weight as light weight response is more dynamic and heavy weight is higher energy

- May go 10 knots above anticipated landing speed
  - Simulates damaged aircraft recovery
  - If the pilot is 75 feet off centerline, the aircraft or pilot may be damaged

Arresting Gear Flight Tests

- Hook functional tests
  - Extend
  - Retract
  - Check position indicators

- High speed engagements may be after a landing
  - Check hook point for touchdown damage

Fuel Subsystem

Fuel Subsystem Overview

- **Store and deliver the proper amount of clean fuel at the correct temperature and pressure to the appropriate tank or engine**

- **Provide positive and reliable fuel flow through all phases of flight including**
  - **Takeoff**
  - **Changes in altitude**
  - **Violent maneuvers**
  - **Sudden acceleration and deceleration**

Fuel Subsystem Overview

412 TW

- **Provide for efficient ground servicing**
  - **Fuel/Defuel**
    - Pressure refueling required for systems over 600 gallons
    - Defuel with gear up desired
    - Ground monitoring and control of tank levels desired
  - **Sump drain**
    - Remove and monitor contaminants, water and microbes
- **Provide fuel to all engines and APU**
  - **One main (feed) tank per engine**
    - Must be able to feed all engines from any main tank
    - Generally one boost pump can supply flow rate for two engines at max power (failure tolerant)
- **Must work in all flight conditions and temperatures**

Fuel Subsystem Overview

- **Have explosion suppression protection features**
  - **Foam or gas inerting**
    - Not all legacy aircraft comply

- **Protect structure from excessive differential pressure**
  - **Vent and pressurization subsystems**

Fuel Subsystem Overview

412 TW

- **Provide fuel dump capability**
  - Takeoff weight usually greater than max landing weight
  - Not all aircraft can dump fuel
- **Provide or respond to CG control commands**
- **Provide heat sink for hydraulics, gear box, generator, avionics (PAO, Freon), FADEC, etc.**
- **All while minimizing pilot workload**

Fuel Quantity and Gauging Subsystem

- **Computes fuel quantity per tank**
  - **Based on fuel level and density**
    - Uses capacitive level probes, densitometers, flow meters
  - **Fuel quantity known to a certain accuracy, may compensate for flight attitude**

- **Fuel System Controller and Panel**
  - **Gathers signals, processes commands, sends info to control panel**
  - **Displays quantities, pressures, x-feed, status indications and all other fuel management functions**
  - **Provides for manual or automatic CG control**

Fuel Vent Subsystem

412 TW

- **Works in conjunction with Pressurization and Explosion subsystems to maintain positive fuel tank pressure**
  - **Vent lines used for each tank may be vented to ambient or ± a few psid using vent (climb/dive) valves**

- **Vent tank stores fuel from thermal expansion or slosh**
  - **Fuel vented overboard if tank is full**

- **Vent system must not permit siphoning or fuel transfer**

Fuel Pressurization Subsystem

412 TW

- **Maintains positive pressure as aircraft climbs, dives, burns fuel and refuels**
  - **Pressure of ullage must be kept within a few psi of ambient air**
    - Wing and tanks may implode or explode due to pressure difference
  - **Must work in conjunction with fuel vent subsystem**

- **Provides force for pressurized fuel transfer**
  - **Pressurization sources include:**
    - Ram air
    - Engine bleed air system
    - Inerting nitrogen

Explosion Suppression Subsystem

412 TW

- Explosion suppression increases survivability by reducing vulnerability
  - Open cell foam, Halon 1301 and inert gas are common
    - Open cell foam and Halon 1301 presents logistical burdens
- Nitrogen enriched air (NEA) pumped into tank
  - Some aircraft use storage bottles others produce NEA
  - Drops O_2 concentration in ullage to below 9%
- On Board Inert Gas Generating System OBBIGS
  - Uses conditioned bleed air run thru Air Separator Module (molecular sieve) to result in NEA
    - O_2 is dumped overboard
    - OBOGGS does the opposite

Engine Feed and Transfer Subsystem

- Moves fuel to engines and between tanks
  - Integral for CG control
  - Any engine must be capable of receiving fuel from any main tank

Fuel Dump Subsystem

- Also called Fuel Jettison Subsystem
- Provides fast and safe unloading of fuel
- A combination of fuel lines, valves and pumps to dump fuel overboard
  - Some aircraft use dedicated dump pumps and hardware
  - Other aircraft use existing transfer subsystem with dump valve, dump manifold and dump mast
- Used by USN/USMC to control landing weight
- Cannot dump all fuel
  - Main (feed) tanks may not have dump capability

Fuel Heat Exchanger Subsystem

412 TW

- Fuel provides heat sink for hydraulics, gear box, generator, avionics cooling (PAO, Freon), FADEC...
- Fuel subsystem generates it's own heat via FADEC and pumps
  - "Fueldraulics" used for many engine controls
- Some aircraft require fuel heaters to thaw ice that would otherwise clog the filters
  - May use engine oil, bleed air or electric heaters

Fuel Subsystem Ground Tests

- **Ground Refuel And Defuel**
  - **Determine max fuel/defuel rates**
  - **Evaluate fueling procedures**
    - Including alternate fueling methods
  - **Hot pit refuel**
    - Combat or Integrated Combat Turnaround
  - **Defuel**
- **Fuel dump, transfer or starvation**
  - **If possible use non-toxic, fire proof fluid**
    - 10/10 oil or ISOPAR-M™ may provide a safer test environment
- **Inerting system – O_2 concentration**
  - **Difficult to measure O_2 in flight**

Fuel Subystem Ground Tests

- **Fuel Transfer**
  - **Evaluate normal fuel management system modes**
    - Automatic and manual transfer functions
    - CG control, etc
  - **Evaluate backup and emergency modes**
    - Failed boost pumps, gravity feed
  - **Determine fuel transfer rates**

- **Evaluate –1 emergency procedures**

Fuel Subsystem Ground Tests

- **Fuel Quantity Calibration**
  - **Weight and Balance hangar**
  - **Varying pitch angle allows for x-y-z cg determination**
  - **Correlate CG indicators with actual CG**
  - **Determine usable and unusable fuel quantity**
    - Correlate usable fuel and indicated quantities
  - **Test at level and varied pitch attitudes and fuel increments**
  - **Measure fuel density and temperature to record test conditions**

Fuel Subsystem Flight Tests

Steady Level Flight

- **Fuel feed and management**
  - Normal and with boost pumps off or simulated failed
  - Main tanks to each engine
  - Monitor engine pump inlet and outlet pressures for cavitation
- **Fuel gauging and Low Fuel warning**
- **Fuel transfer**
  - Normal and transfer pumps off or simulated failed
- **CG control**
  - Auto and manual

Fuel Subsystem Flight Tests

Climb and Descent

- Feed and transfer
- Pressurization, Venting, Inerting
  - Difficult to measure O_2 in flight
- Max power, mil power climb
  - Boost pumps on and off
- Idle descent
  - Nominal and one pressurization system failed

Fuel Subsystem Flight Tests

412 TW

Maneuvering

- Pressurization and venting under extreme conditions
- Throttle excursions
  - Boost pumps on and off
- All maneuvers up to aircraft limits
  - Sideslips, pushovers, max roll rate, inverted, zoom climb/dive, extreme attitudes, weapons pass
- Fuel quantity accuracy
- No unexpected venting or fuel transfer

Fuel Subsystem Flight Tests

- **Fuel Dump**
  - **Determine dump rates**
  - **Evaluate procedures and safety**
- **Inerting subsystem**
  - **Oxygen concentration difficult to measure in flight**
    - Measure before and after flight and keep track of fuel burn, pressurization and venting
    - Research underway to permit in flight measurement
    - Anyone got any ideas?
  - **Capacity - rapid descent is stressor**

Fuel Subsystem Flight Tests

412 TW

- **Cross feed during transients**
  - **Any engine from any tank**
  - **Adequate fuel flow**
  - **Throttle transients, pumps switched on and off**

- **Alternate fuels**
  - **JP-4 phased out**
  - **JP-5, NATO F35, JET A (A-1), Jet B etc.**
  - **Lots of alternate fuels in the news**
    - Long term effects difficult to flight test quickly

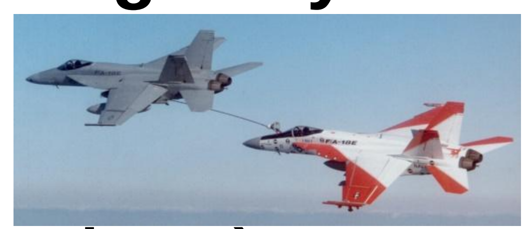
Aerial Refueling Subsystem

Aerial Refueling System Overview

412 TW

- **Universal Air Refueling Receptacle Slipway Installation (UARRSI) feeds into refueling system plumbing**
  - **Boom equipped tanker required**
  - **High flow rates (8,000 lbs per minute)**
  - **USAF F-35A**

- **Most aircraft use probe and drogue system**
  - **Smaller deck requirement**
  - **Buddy store can be used**
  - **Lower flow rates (2,000 lbs per minute)**
  - **USMC/USN F-35B/C**

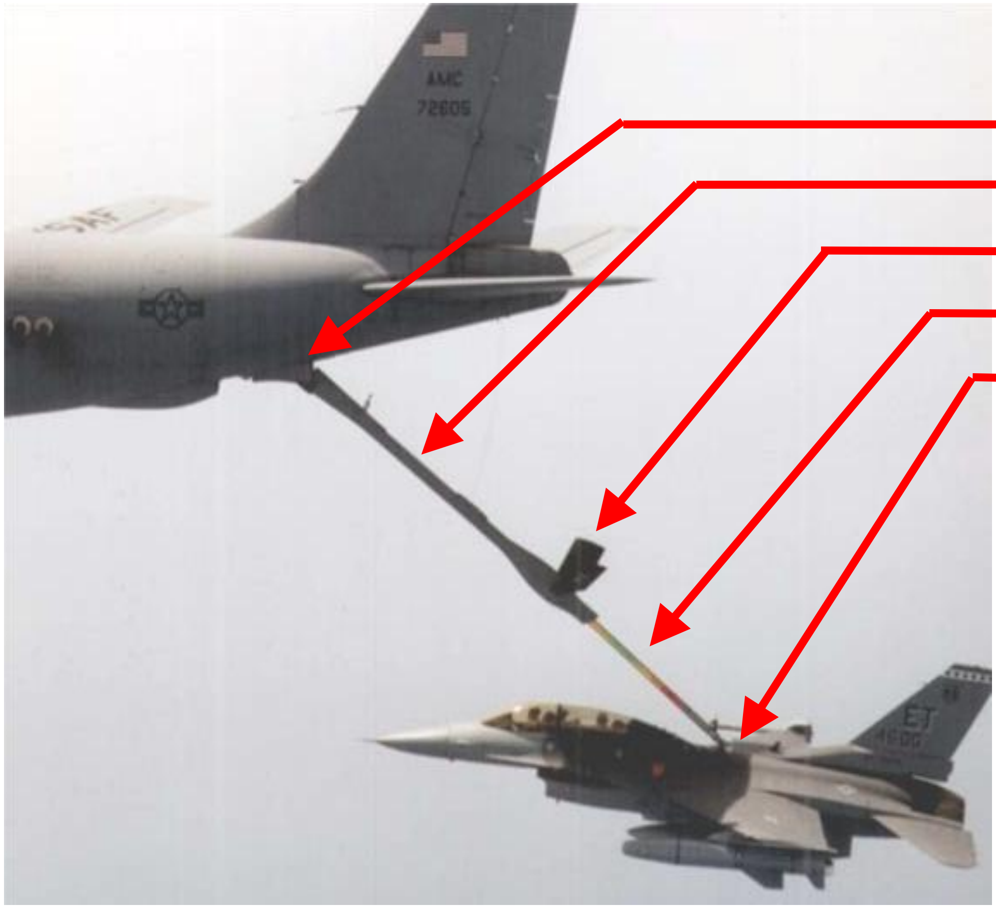


Aerial Refueling System Overview

- **Aerial refueling involves a system of systems**
  - **AR Subsystems on each aircraft**
    - Fuel
    - Hydraulics
    - Electrical
    - Pneumatics
  - **AR Interfaces between different aircraft**
    - Physical
    - Communications
      - Boom Signal System
      - Radio
      - Boom Interphone
    - Aerodynamic
    - Visual

Aerial Refueling System Overview

412 TW



Boom

- Yoke & trunion (pivot)
- Structural tube
- Control surfaces
- Telescoping tube
- Nozzle

Receptacle

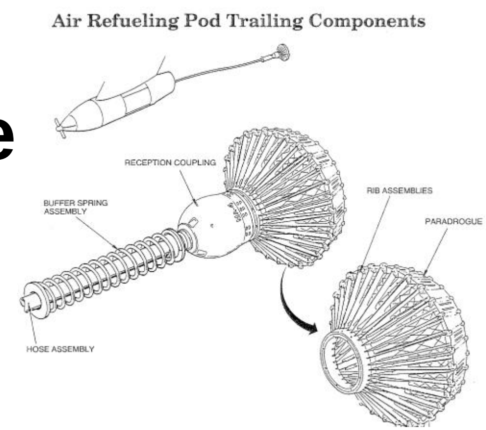
- Built into UARRSI
- Location and configuration vary
- May have a door
- Lighting

Aerial Refueling System Overview

- **Boom Contacts**
  - **Receiver pilot positions aircraft behind tanker**
  - **Boom operator controls boom and makes the contact**
  - **Receiver pilot maintains position until transfer is complete**
  - **Refueling often performed in a turn**
    - Racetrack refueling pattern keeps tankers near the action

Aerial Refueling System Overview

- **Probe is on the receiver aircraft**
  - **Probe mast**
    - Can be fixed or retractable
  - **Nozzle**



- **Drogue is attached to trailing hose**
  - **Stabilizes hose**
  - **Provides resistive force**
  - **Contains coupling**

- **Receiver pilot flies probe into the drogue**

Aerial Refueling System Ground Tests

412 TW

- **Boom and UARRSI compatibility**
  - Tanker parked high, receiver parked low
  - Can check hook up and limited flow rate operations

- **Probe and drogue compatibility**
  - Form and fit check

Aerial Refueling System Flight Test

412 TW

- **Subsystem considerations for both tanker and receiver**
  - **Fit and function**
    - Mechanical
    - Proper clearances in/near contact
  - **Fuel System**
    - Flow rates and pressures
      - Variable number of pumps
    - Surge pressures
      - Pump turn-on, tank shutoff, high-level shutoff
  - **EMI / EMC**

Aerial Refueling System Flight Test

- **Other discipline considerations for both tanker and receiver**
  - **Performance**
    - Determine refueling envelope
  - **Handling qualities**
    - Approach
    - Connect
    - Breakaway
    - Adverse wake effects
  - **Human factors**
    - Visual cues
    - Lighting and finish acceptability for night refueling
  - **Communication**
    - Boom interphone, radios

Aerial Refueling System New Receiver

- **Boom – Receptacle mechanical compatibility**
  - **Physical clearances in / near contact**
    - Canopy
    - Antennas
    - Aircraft structure / control surfaces

- **Nozzle / receptacle loads**
  - **Nozzle engagements / disengagements**
  - **Induced loads**
  - **Tension disconnects**

Impact Loads	2,000 lbf Laterally 5,000 lbf Vertically
Boom Strike (perimeter)	750 lbf Laterally 1,800 lbf Vertically
Contact	20,000 lbf
Transfer	9,000 lbf
Tension Disconnect	14,000 lbf

<u>"Graceful" Degradation</u>

Normal Disconnect	0 lbf
Good Tension Disconnect	< 9000 lbf
Toggle Failure	~ 11,000 lbf
Boom Failure	~ 14,000 lbf
Receiver Structural Failure	> 20,000 lbf

Aerial Refueling System New Receiver

412 TW

- **Probe – Drogue Mechanical compatibility**
  - **Physical clearances per STANAG 3447**
- **Probe - coupling loads**
  - **Engagements / disengagements**
    - Fuel pressure increases force required
    - Engagement ~ 150 lbf, with no fuel pressure
      - Increases ~ 5 lbf per psi in coupling
    - Disconnect - 420 lbf, with no fuel pressure
      - Increases ~ 4 lbf per psi in coupling
  - **Induced probe mast loads**
    - Aero loads
    - Contact loads
    - Off-center disconnects

Aerial Refueling System New Receiver

- **Fuel System**
  - **Fuel Pressures**
    - Operating (90 psi) : Normal Operation
    - Proof (180 psi) : Some leakage / deformation
      - Must be greater than max encountered surge
    - Burst (270 psi): System failure
  - **Surges**
    - Valve Closures
    - Pump Starts
    - Flowing Disconnects
  - **Fuel Management**
    - CG control
    - Valve control
    - Reverse AR

Aerial Refueling System
New Receiver

- **Aero Performance**
  - **HQ Questionnaire / Cooper-Harper**
    - Flight control response
    - Power available
    - Throttle response
  - **Boom - Receptacle**
    - Boom control
    - Adverse airflow
    - Bow wave effects
  - **Probe Drogue**
    - Bow Wave
    - Downwash

Aerial Refueling System New Receiver

- **Human Factors**
  - **Visual Cues**
    - Situational awareness
    - Lead-in lines
    - Paint scheme
  - **Night Lighting**
    - Boom – Receptacle
      - Boom nozzle light, tail mounted flood
      - Marker lights / dayglow markings
      - Receptacle / area lights
      - General area lights
  - **Probe – Drogue**
    - Exit light
    - Hose / probe illumination

Aerial Refueling System New Receiver

- **Communications**
  - Boom signal system
  - Radio
  - Boom interphone

- **EMI / EMC**
  - Tanker to Receiver
  - Receiver to Tanker

Aerial Refueling System New Tanker

412 TW

- **Similar to New Receiver except:**
  - **Mechanical Compatibility**
    - Boom and drogue loads per MIL-S-8865/008865
  - **Fuel System**
    - Fuel Pressures
      - Operating 120 psi
      - Proof 240 psi
      - Burst 360 psi
    - Off-Load Rates
      - Boom 8000 lb/min
      - Drogue 2000 lb/min

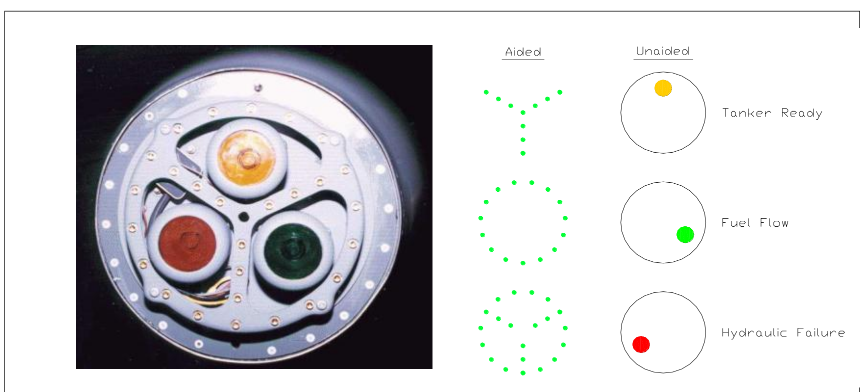
Aerial Refueling System
New Tanker

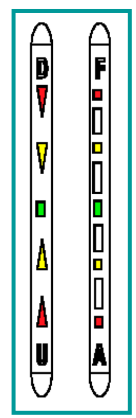
412 TW

- **Similar to New Receiver except:**
  - **Aero Performance**
    - Tanker handling qualities
      - Autopilot on/off
      - HQ Questionnaire
      - Cooper-Harper Scale
  - **Boom**
    - Control authority throughout envelope
  - **Drogue**
    - Extend, trail, and retract
    - Hose response

Aerial Refueling System
New Tanker

- **Similar to New Receiver except:**
  - **System Directional Lighting**
    - Boom pilot director lights
    - Drogue system status lights
    - Other receiver visual aids
    - Night lighting





Hydraulic Subsystem

412 TW

Hydraulic Subsystem Overview

- **Provide large forces remote from the engines**
  - **Precise and rapid response applications**
    - Flight controls and brakes
  - **Low precision and speed applications**
    - Landing gear, cargo ramps and miscellaneous doors
  - **High flow rate applications**
    - Guns and emergency generator
- **Relatively small weight penalty**
- **Must operate at all temperatures**
  - **Both specified and encountered**

Hydraulic Subsystem Overview

412 TW

- USAF systems are usually 3,000 or 4,000 psi
- Fluid properties vary
  - Type / Temp range / Applications

Type	Temp range	Applications
I	-65 to +160 °F	Helicopters
II	-65 to +275 °F	Legacy aircraft
III	-65 to +390 °F	Modern aircraft (not Global Hawk)

Type II:
Mil-H-5606, Standard prior to 1974, Petroleum base, fire hazard
Mil-H-87257, Synthetic hydrocarbon base , Good viscosity at low temperatures

Type III:
Mil-H-83282, Synthetic hydrocarbon base, more fire resistant and stable, poor viscosity at -60°F

Hydraulic Subsystem Overview

412 TW

- **Heat must be controlled and dumped**
  - **Hydraulic, fuel, ECS and avionics generate heat**
  - **Hydro and fuel temps must remain within limits**
    - High temps degrade fluid and reduce component life
    - Fuel often used as heat sink
    - High heat sink temps may lead to avionics shutdown

- **High speed flight limits air cooling**
  - **@ Mach 2 and 40,000 feet, total air temp is ~ 255°F**

- **Cold Temperatures = High Fluid Viscosity**
  - **Low speed, high altitude flight**
    - @ 40,000 feet outside air temp is approx -38°F
  - **Cold soak on the ground**
    - Cold Mil-H-83282 (Type III fluid) flows like molasses

Primary Hydraulic Pumps

- **Pump outlet usually connected to hose**
  - **Reduce outlet pressure pulsations (ripple)**
- **Case drain filtered and sent to reservoir**
  - **Helps cool pump in no flow condition**
  - **Warms pump and fluid after cold soak**
  - **Key location to monitor fluid temps, can show pump degradation**

Secondary Hydraulic Power Sources

412 TW

- APU and Ground Carts
  - APU may be used in air
- Electrical motor pumps
  - Integrated AC or DC motor and hydraulic pump
  - Used to supplement engine driven pumps in high demand cases
  - Provide power during engine off conditions
  - High power requirements, relatively low flow rate

Secondary Hydraulic Power Sources

- **Ram Air Turbine (RAT)**
  - **Podded propeller and pump inserted in air stream**
    - Inadvertent ground deployment can be dangerous
  - **Emergency power system – low flow rate**
- **Transfer pump**
  - **Transfers power from one hydraulic system to another via reversible motor pumps connected by a shaft**
  - **No transfer of fluid**
  - **No mutual leak path**
- **Other devices could be bleed air turbine driven**

Fluid Loss and Leak Detection Subsystem

- Monitors reservoir levels and compares to predicted levels based on system state
  - Actuator and shutoff valve positions
  - Preflight conditions
  - Return pressure drops also used to detect leaks
- System branches may be cut-off by shutoff valves to isolate leak
  - A branch is shutoff and response measured
  - Starts with lowest impact system and works up to flight controls
- Hydraulic fuses shut off if flow rates are too high

Hydraulic Subsystem Ground Tests

- Basic Functionality
  - Good chance for first look at hydraulic system and any problems that surface early
  - Flush and fill at factory
  - Operation on Ground Cart power
- Take advantage of engine run ground tests whenever possible
  - Learn the system then see it in action

Hydraulic Subsystem Ground Tests

- **Basic Operations**
  - **APU operations**
  - **Engine Runs**
  - **Flight control surface movements**
  - **Gear swings, etc.**
  - **Exercise all systems whenever possible**
    - Learn system response
    - Force infant mortalities

Hydraulic Subsystem Flight Tests

- **Landing gear and flap retract/extend times**
  - **Alternate or emergency methods if available**
    - Wing bending may be different in flight then on jacks
- **Fluid temps within limits**
  - **Stressors include**
    - High speed and high altitude flight
    - On the ground on a hot day
- **Normal operation of idle components after prolonged cold soak at altitude**
  - **Refueling doors, landing gear, nose wheel steering and brakes**
    - Dead end systems are of particular concern
    - May have limited leak path in actuator to provide warm flow

Hydraulic Subsystem Flight Tests

412 TW

- Fluid Loss and Leak Detection response to actuator movement
- Failure modes and power by alternate means
  - Turning off pumps is not a popular test
  - APU
  - Transfer Pump
  - RAT
- Flying qualities
  - Good chance to look at g tolerance and transient pressures at the flight control valve inlets
  - High AOA tests typically involves large actuator transients and high associated flow requirements

Environmental Control System

Environmental Control System Overview

- **Environmental Control Systems provide:**
  - **Distribution of engine bleed air**
  - **Cooling, heating, ventilation, contamination protection and moisture control of occupied compartments, equipment and avionics**
  - **Pressurization of g-suits, pressure suits, inflatable seals, reservoirs, etc**
  - **Anti-icing and de-icing protection**
  - **De-fogging of mission essential transparencies**
  - **Precipitation and contamination removal from windshields and other transparent surfaces**
  - **Oxygen to aircrew and passengers**

Environmental Control System Bleed Air Subsystem

- **Provides pressurized air for all subsystems**
  - **Used to start engines, purge gun gas, disrupt nacelle to ground vortices, etc**
- **Uses compressor air from engine, APU or ground cart**
  - **Source may be high pressure, high temperature (900 °F)**
- **Controller and manifold have overheat sensing**
  - **Leak and fire detection elements may have only on-off indications - not specific leak locations**

Environmental Control System Bleed Air Subsystem

- **General Requirements derived from:**
  - **MIL-E-38453**
  - **Contract Air Vehicle Specifications**
  - **Operational Requirements Document**

- **Will system provide right temp, pressure and flow rate to using components throughout the operational envelope?**

Environmental Control System Ground and Flight Tests

- Typical test procedures
  - Exercise all normal aircraft operational modes
  - Measure flows, temps and pressures
  - Verify system controls all cooling loops according to expected logic
  - Verify heat loads are as predicted and cooled to expected levels
  - Smoke and fume elimination testing
  - Additional stressor tests at Climatic Lab and during all weather deployments

Environmental Control System Ground and Flight Tests

412 TW

- Design point thermal tests help verify models
  - Hot day ground cabin cooling
  - Cold day ground cabin heating
  - High altitude cabin heating
  - Humid day
    - Water removal
    - De-fog
  - Cabin Temperature control (hi-low, floor heat)
  - Ram air cooling tests
    - ECS shutdown configuration

Bleed Air Subsystem Flight Testing

- Bleed air monitored on every flight
- Test points usually piggy-backed to other ECS tests or types of missions
  - High alpha
  - Cruise
  - High/low altitudes and speeds
- Things to watch
  - Temps on both sides of heat exchangers do not exceed maximum allowable
  - Adequate pressure to start engines and operate all using components
  - Can smoothly switch between engine operating stages
    - Start through shutdown

Air Conditioning and Pressurization Testing

- **Functions usually tested include**
  - **Cabin altitude control -1,000 to +10,000 feet**
  - **Cabin rate control in a climb, descent and dive**
    - Normal settings 500 fpm ascent, 300 fpm descent
    - Can range up to 2000 fpm – hard on the ears
  - **Negative pressure relief, over-pressure relief, maximum delta P flight condition**
  - **Fuselage leak rate**
  - **Pressure transients due to throttle and airspeed changes**
  - **Safe depressurization after touchdown**
  - **Single pack modes, display and control functionality**

Anti-ice and De-ice Subsystem

- **Anti-ice prevents ice from forming, De-ice gets rid of ice after it forms**
  - **Mostly climb, cruise and descent below 20,000 feet**
  - **Two types of Anti-ice**
    - Evaporative – enough heat to evaporate ice on contact
    - Running-wet – enough heat to prevent freezing
- **Typically required for:**
  - **Wing and tail leading edges**
  - **Engine air inlet, air scoops and guide vanes**
  - **Mission essential transparent surfaces**
  - **Pitot systems**
  - **Radomes**

Anti-ice and De-ice Subsystem

- **Tested on ground in climatic lab and cold weather deployment**
- **Tested in air by natural icing and/or airborne icing tanker**
  - **Helicopter**
  - **Fixed wing**

De-fog Subsystem Overview

412 TW

- **Required for mission essential transparencies:**
  - **Taxi**
  - **Evasive action**
  - **Formation flying**
  - **Camera, astrodome and viewing stations**
  - **Checking of engines and flight control surfaces**
- **Typically accomplished with:**
  - **Hot air jets, double panes windows w/ hot air in between or dry air insulating gap**
  - **Electrical conductive coatings**
    - Usually integral to transparency
  - **Humidity control of cabin air – or any combo of the above**

De-fog Subsystem Flight Tests

412 TW

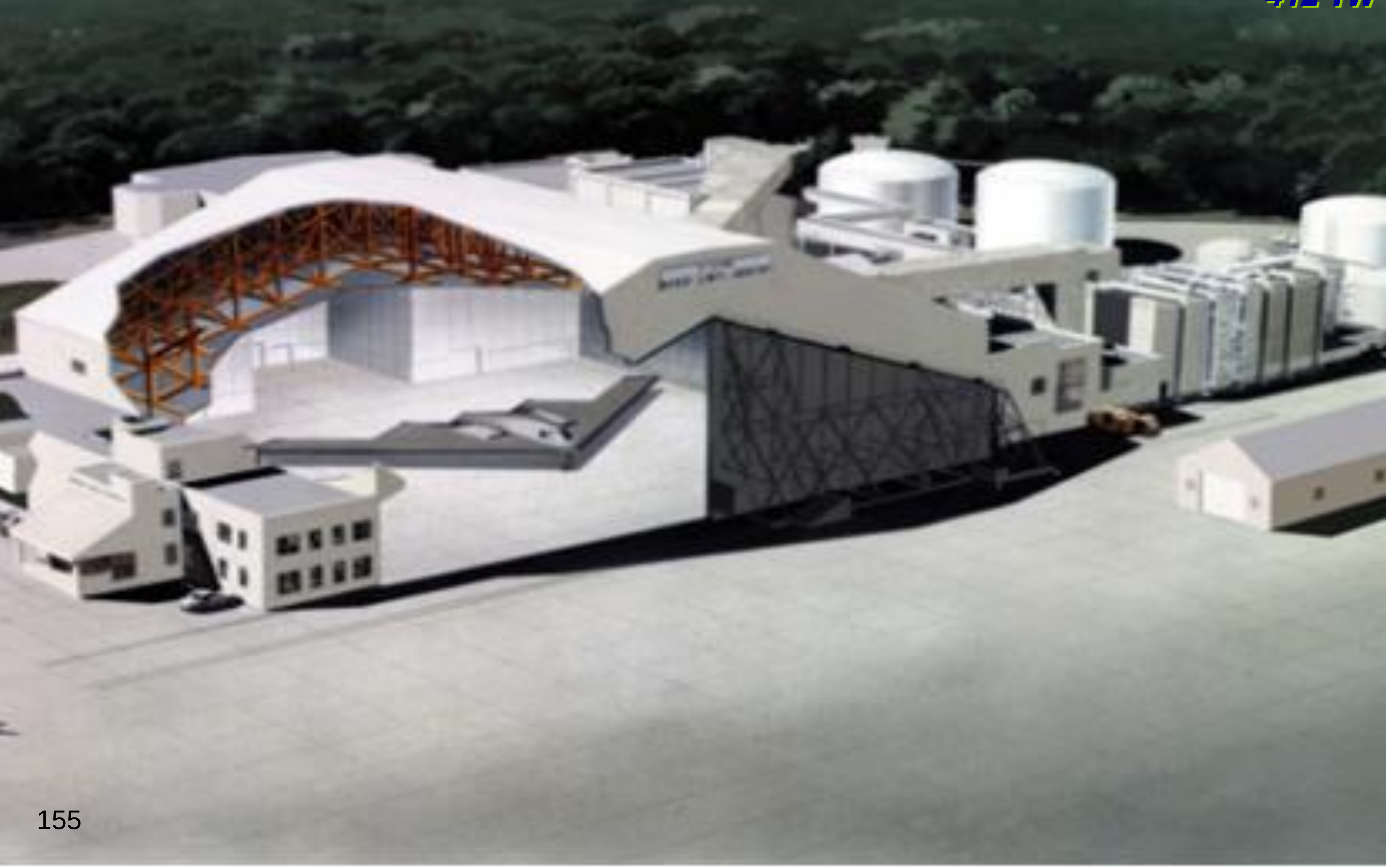
- **Tested in day to day ops and climatic and all weather testing**
- **Rapid descent after cold soak a stressor case**
- **Usually controlled by ECS computer or pilot**
  - **Temperature of air supply controlled or monitored**
  - **Temperature of transparency may be monitored**
    - Too hot - may have thermal damage
    - Too cold - may lose impact resistance

Rain and Contaminant Removal Subsystem

- Typical methods include:
  - Hot air jets
    - Also provides anti-ice
  - Ground applied repellant
  - In flight applied repellant
  - Wipers and repellent
  - Nothing - rely on slippery transparency surface
- Tested on ground in climatic lab and all weather deployment
- Tested in natural conditions and/or by water spray tanker

Climatic Lab Tests

412 TW



Climatic Lab Tests

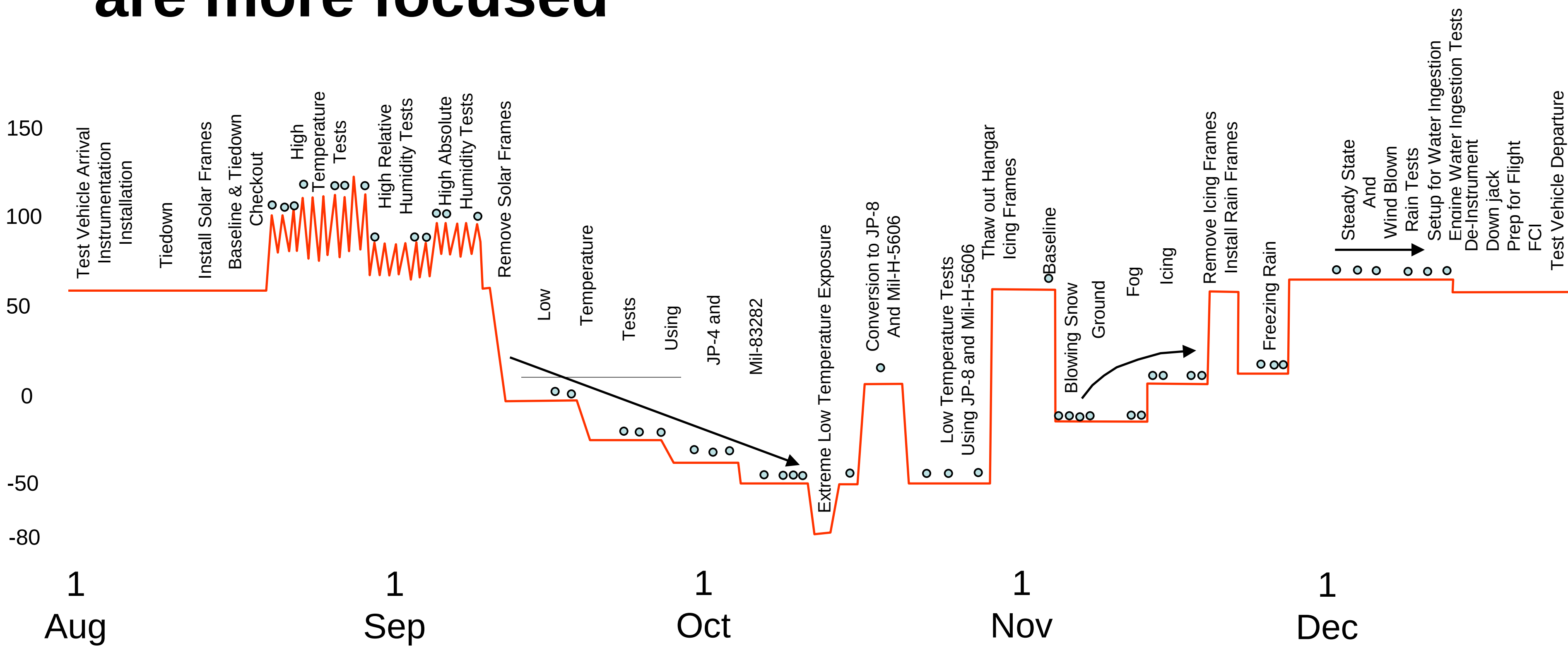
412 TW

- **McKinley Climatic Laboratory, Eglin AFB, Florida**
  - **Part of the 46th Test Wing**
    - Can be used by US government agencies and private industry
    - Boeing 787 is testing there now
  - **World's premier climatic lab**
    - -65 to 165° F
    - Freezing Rain
    - Snow
    - Sand, Wind, Rain and Dust (SWRD)
    - Solar Radiation
    - Rain Ingestion and Intrusion
    - Salt Fog
    - Can run engines with aircraft on jacks or in flight mode

Typical Climatic Lab Test Profile

412 TW

- **Test conditions can be tailored to project needs**
- **This is a complete evaluation, some programs are more focused**



Typical Climatic Lab Subsystem Tests

412 TW

- Auxiliary Power Unit / Engine Start Sequence
- Hydraulic / Mechanical Systems
  - Landing Gear
  - Flight Control Response
  - Wing Sweep
  - Heating and Cooling Loads
  - Static Weapons Release
- Environmental Control System
  - Ground and limited flight operations
- Electrical System
  - Cold and hot weather operations

Typical Climatic Lab Tests

412 TW

- **Airframe Integrity**
  - Water intrusion
  - Ground de-ice
  - Snow removal
- **Ground support equipment**
  - Can you hook up power and start the aircraft
- **Technical Order Verification and Validation**
  - Are the adverse weather procedures correct
- **Human Factors**
  - Can the aircraft be supported in the fleet

Climatic Laboratory Advantages and Limitations

412 TW

- **Advantages**
  - Flexible scheduling
  - Controlled condition and buildup to extremes
  - Maximizes information return
  - Identifies hazard prior to all-weather operation

- **Limitations**
  - Cannot fly or taxi
  - No dynamic loads or aerodynamic effects
  - Laboratory has finite conditioned air capacity
  - Cannot adequately evaluate avionics
  - Cannot evaluate erosion from rain or sand

All Weather Test

412 TW

All Weather Test Overview

- **Adverse weather happens**
  - **Evaluate performance in peace time**
    - The aircraft will eventually operate in adverse weather
- **Real world simulated ops in the real world**
  - **Evaluate specification capabilities**
  - **Evaluate integration of systems**
  - **Determine if mission requirements are met**
  - **Develop flight manual adverse weather procedures**
  - **Verify and validate technical order procedures**
  - **Develop work around procedures**
  - **Assess durability, reliability and maintainability**
  - **Assess support equipment adequacy**

All Weather Test Advantages and Limitations

- **Advantages**
  - Natural environment
  - Operational missions
  - Integrated weapon system evaluation
  - Real taxi and flight conditions
  - Assess airframe durability
  - Specific subsystem flight tests
  - Human factors evaluation under realistic conditions
- **Limitations**
  - Fixed test window
  - Weather is variable

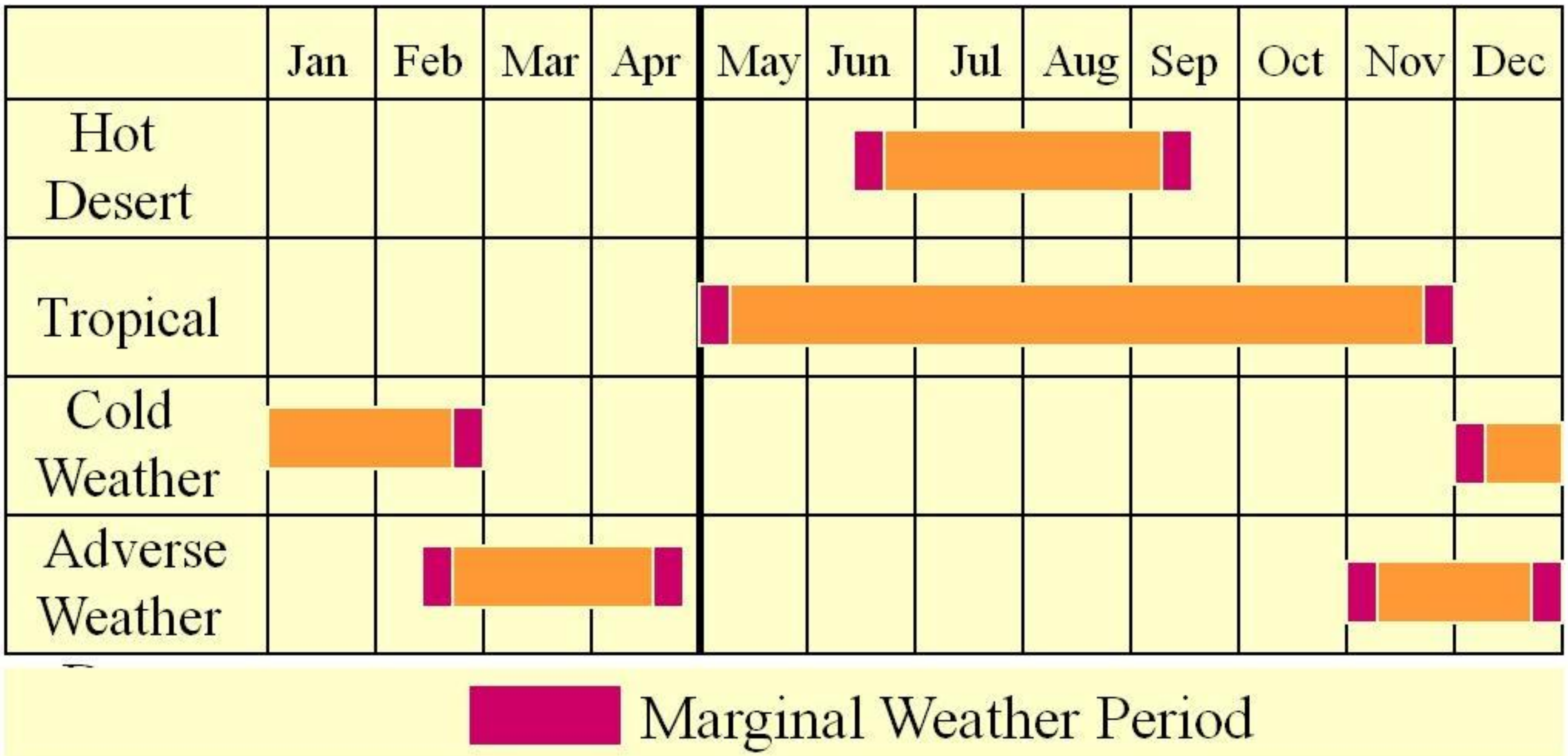
All Weather Test Deployment Locations

412 TW

- **Hot/Desert**
  - Yuma Proving Grounds, AZ
  - Naval Air Station El Centro, CA
- **Tropical**
  - Anderson AB, Guam
- **Arctic**
  - Eielson AFB, Alaska
- **Adverse**
  - Billy Mitchell Field, Milwaukee, WI
  - Bodo AB, Norway

All Weather Test Deployment Windows

412 TW



Questions?