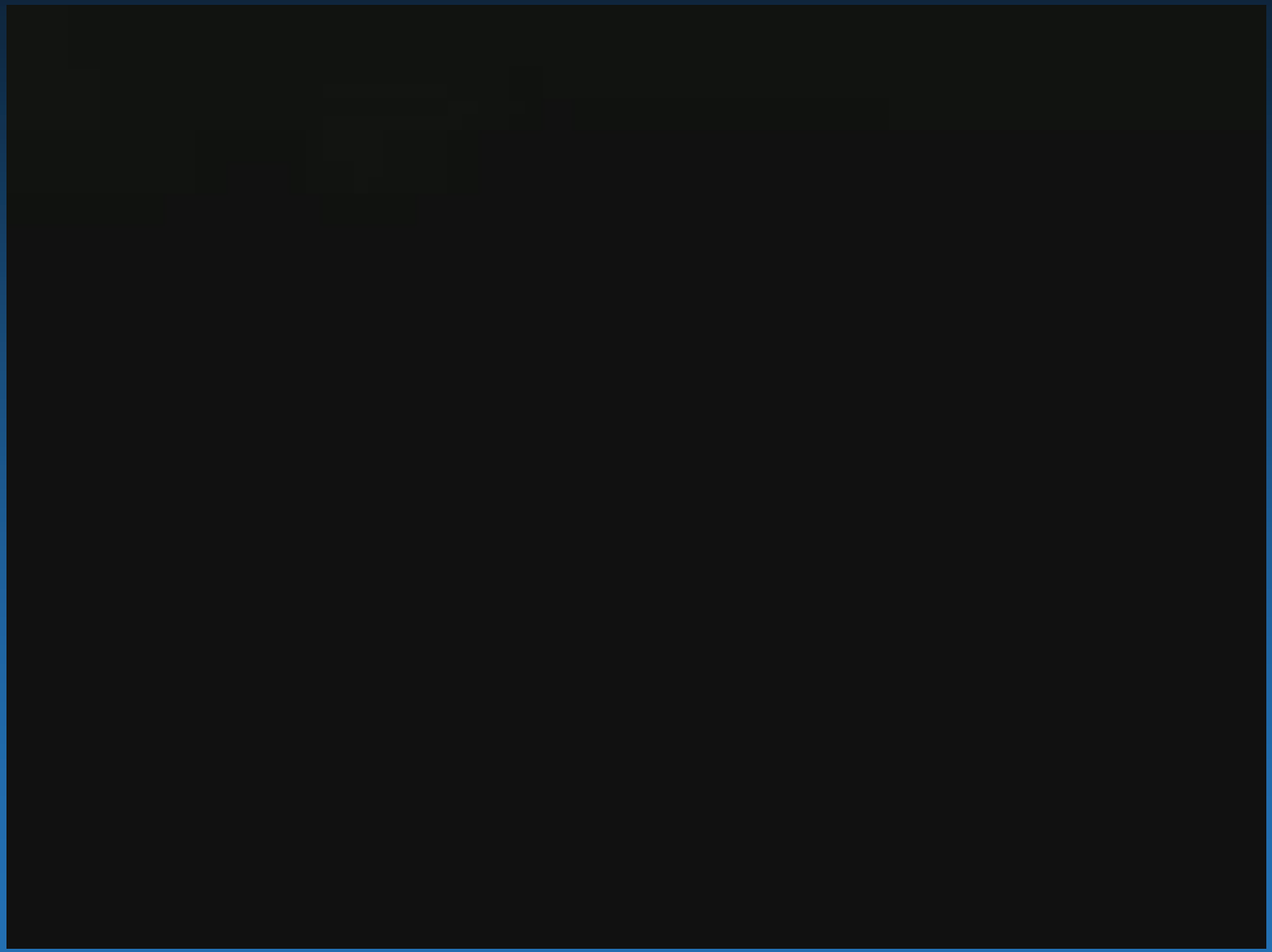
F-16 E/F Automatic Terrain Following Development:

"It's Not Over Till It's Over"

Billie Flynn

Experimental Test Pilot

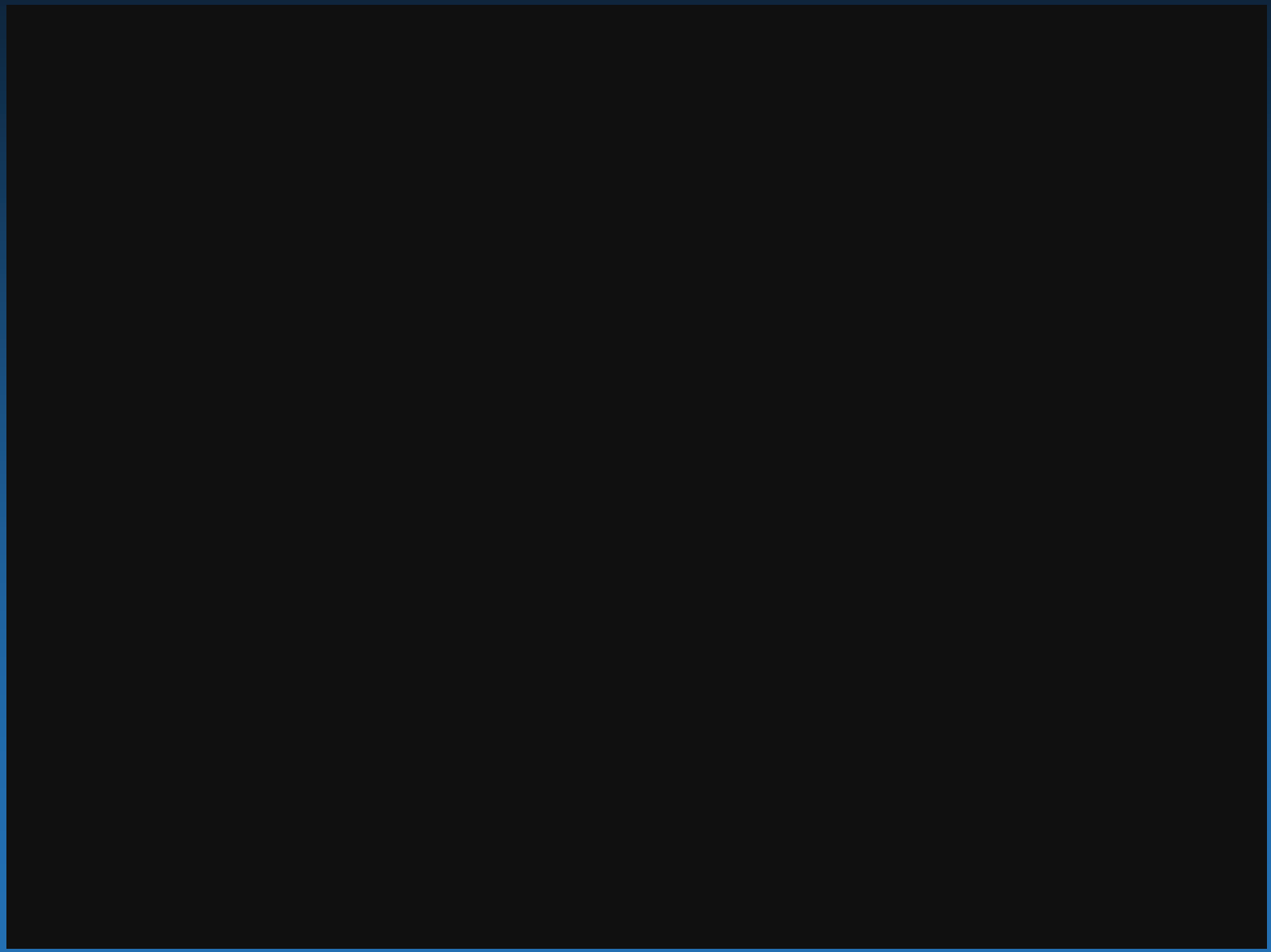
Lockheed Martin Aeronautics Company



Overview

- Super Viper Description
- TF Overview
- RTF Overwater Incident
- DBTF Desert Butte Incident
- Summary
- Lessons Re-Learned
- ???

Video Conferencing



F-16 E/F – A New Fighter

NEW AVIONICS
- Mission Computer
- Color Display Processor
- Fiber Optic Architecture
- Data Link, Com & Nav System
- IFF Interrogator

ADVANCED SENSORS
- Agile Beam Radar
- Integrated FLIR & Targeting System
- Radar Auto Terrain Following
- Internal Electronic Warfare Suite
- Countermeasures Dispenser System

ADVANCED COCKPIT
- Revamped Pilot Interface
- Color Glass Cockpit

PROPULSION
- F110-GE-132
- Autothrottle

FLIGHT CONTROL SYSTEMS
- Upgraded Digital Flight Controls
- New Air Data System
- Next Generation Autopilot
- Auto Ground Collision Avoidance System
- Pilot Activated Recovery System
- Auto Deep Stall Recovery

AIRFRAME/ SYSTEMS
- 50,000 lb Max TOGW
- 44,500 lb Max Landing Wt
- Dual ECS
- NVIS Exterior / Strip Lighting
- Equipment Dorsal
- Conformal Fuel Tanks

Full Color, All Digital Cockpit

- **Three 5 x 7 inch Primary Multi-Function Color Displays**
- **Windowing Capability, Nine Displays Within Three**
- **Fused Sensor Data Presented Pilot**
- **Intuitive HOTAS Controls Optimized Through Combat Operations**
- **Fully NVIS Compatible**

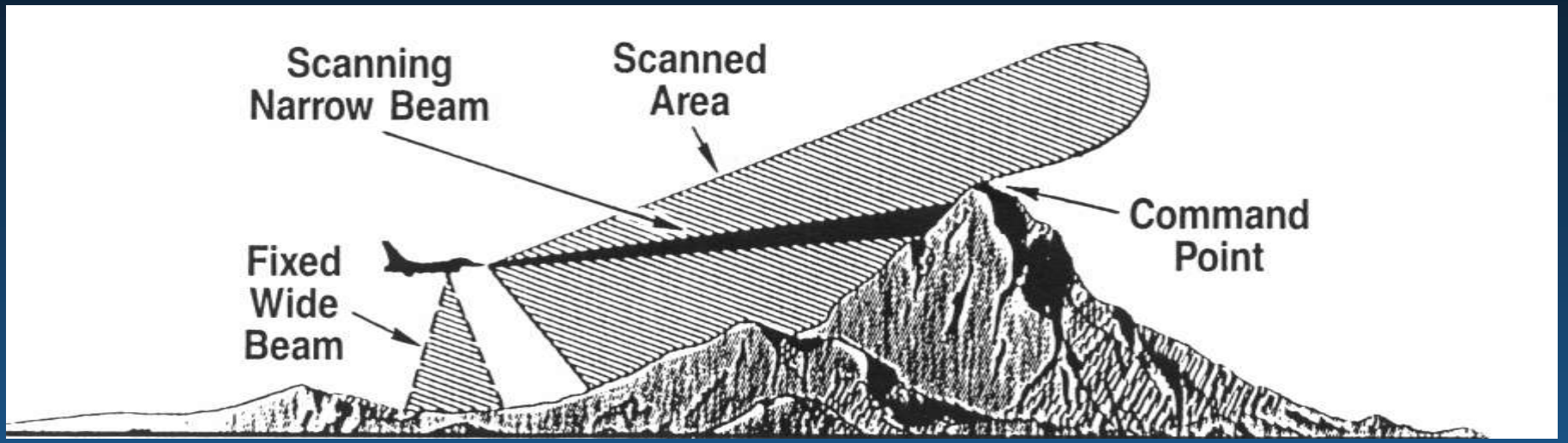
Combat-Optimized Man Machine Interface

PVI – Sometimes Nothing Helps

Terrain Following (TF) Capabilities

- **Radar Terrain Following (RTF) – Active mode**
  - ***Stand-alone or interleaved radar modes***
- **Database Terrain Following (DBTF) – Passive mode**
- **Manual or automatic capability with autopilot modes**
  - ***Fully coupled operation***
- **System Wide Integrity Monitoring for fault detection**
- **RTF / DBTF - Integrated operation**

Radar Terrain Following

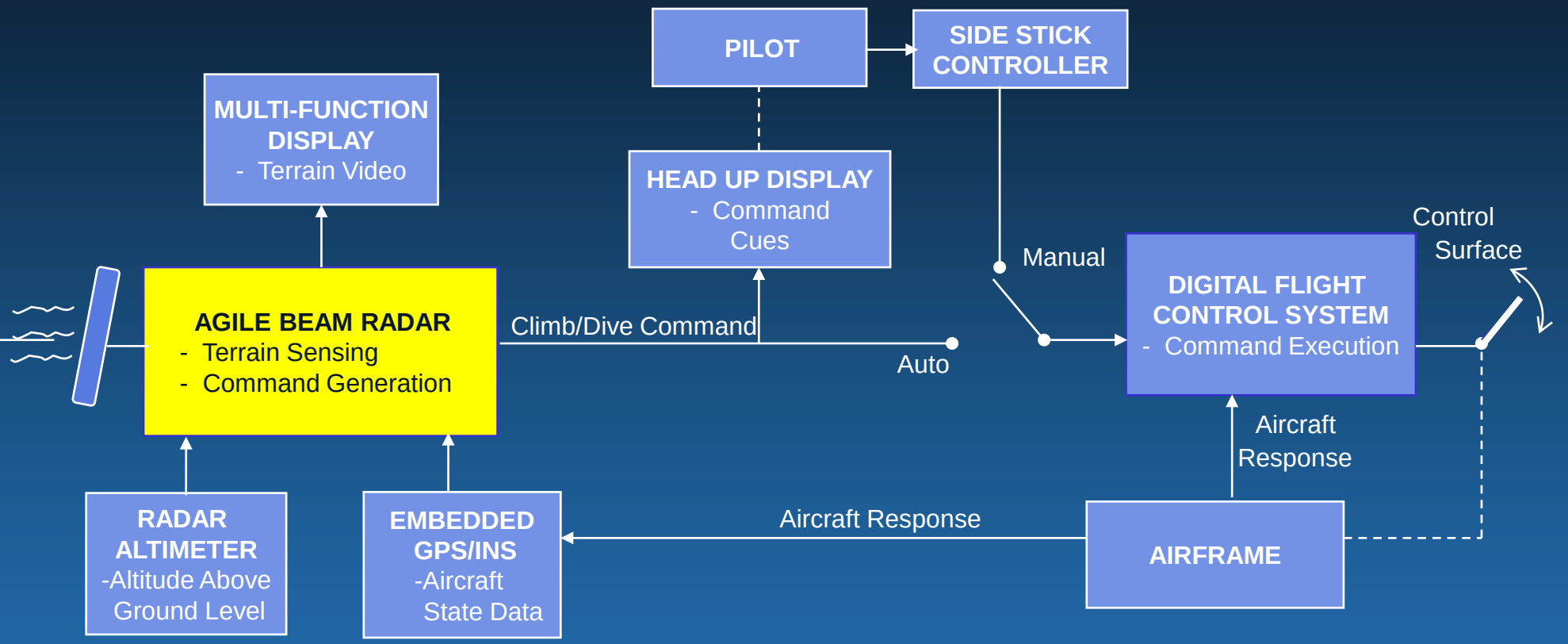


- **Radar senses terrain and generates climb / dive commands at selected Set Clearance Plane (SCP)**

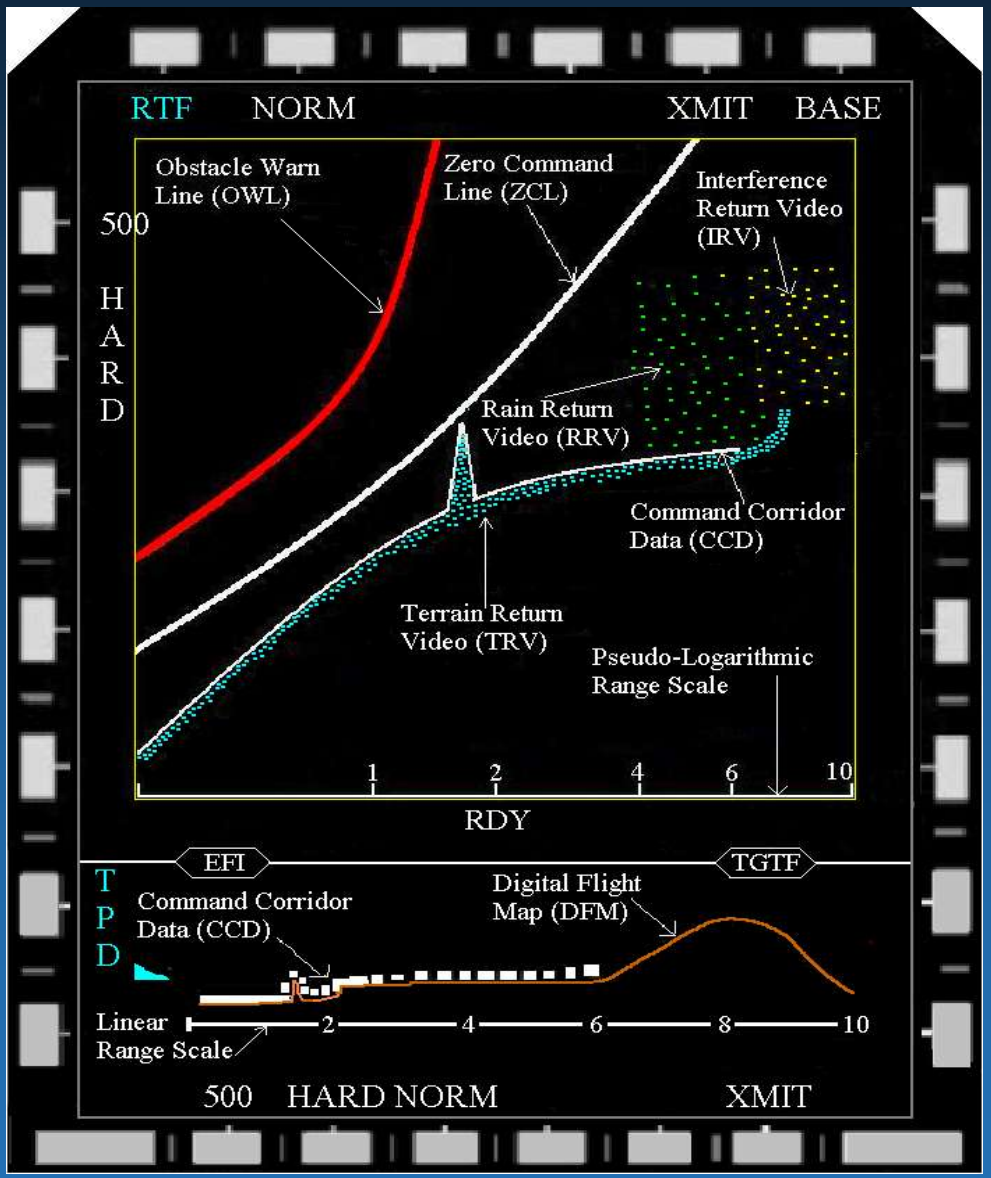
- **Flight control system (FLCS) follows commands from radar computer**
  - ***Control stick coupling of displayed commands in Manual RTF***
  - ***Direct coupling in Automatic RTF***

- **Radar Altimeter**
  - ***Checks operation as back-up to radar***

RTF System Block Diagram



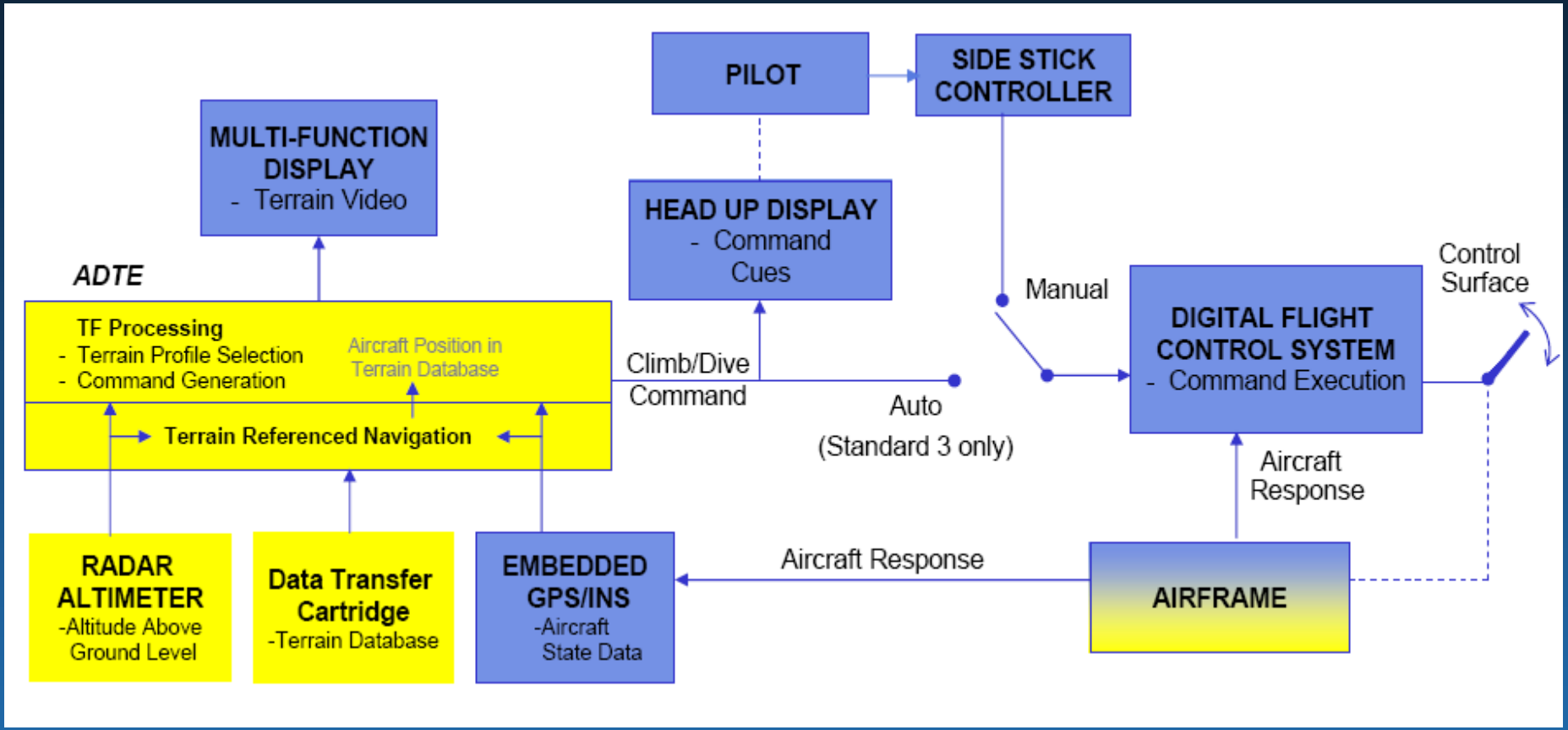
‘E-Squared’ and Terrain Profile Display



Data Base Terrain Following

- Digital Terrain Elevation Database (DTED)
  - *Scanned to generate 2D Worst Case Profile (WCP) of Terrain*
- DBTF algorithm scans WCP
  - *Generates climb / dive commands at selected Threshold Crossing Height (TCH)*
- FLCS follows commands from digital terrain system (DTS) flight software
  - *Control stick coupling of displayed commands in Manual TF*
  - *Direct coupling in Automatic TF*
- Radar Altimeter
  - *Checks operation as back-up to DTS*

DBTF Functional Block Diagram



Who Needs Pilots Anyway???

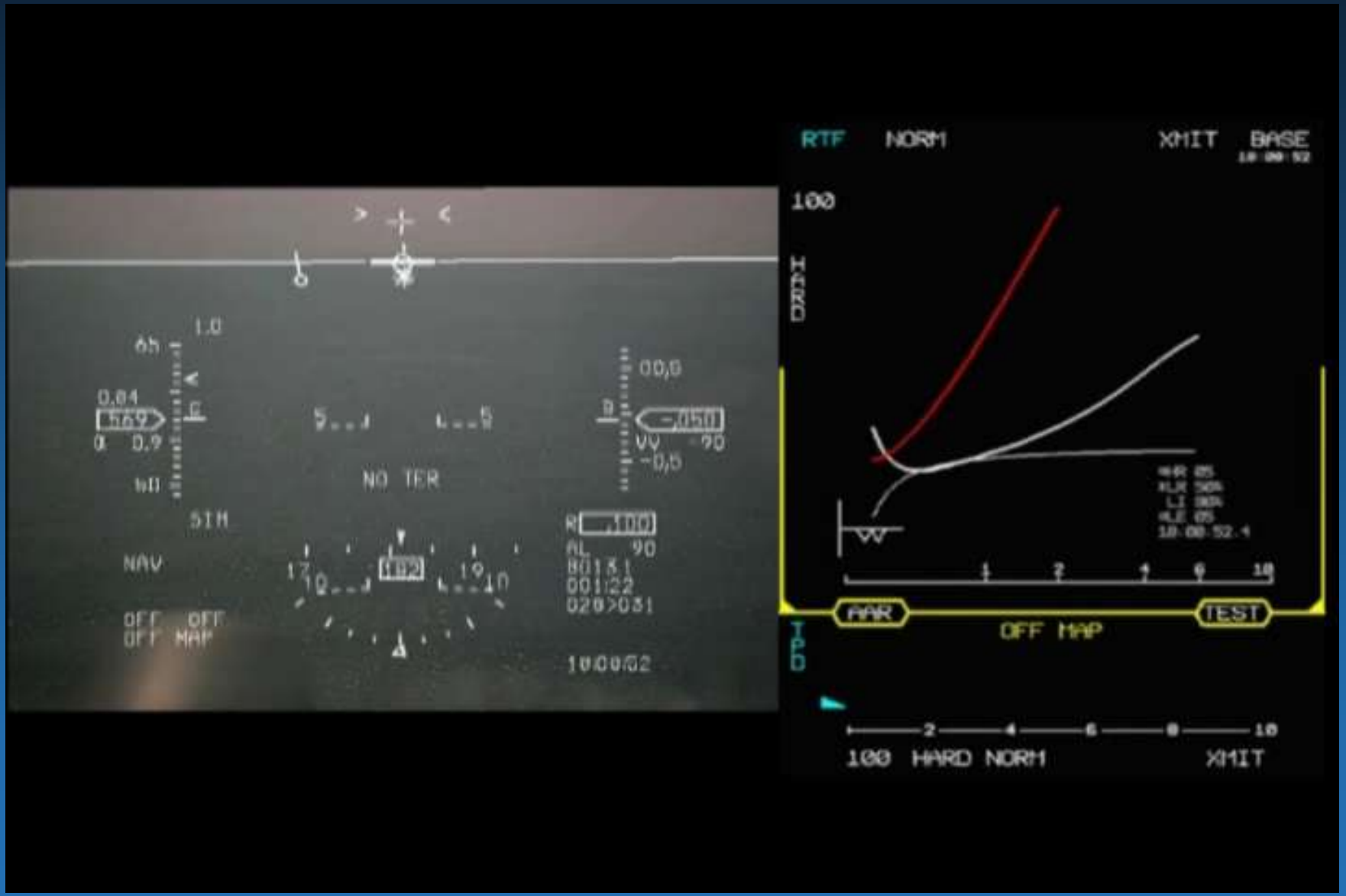
RTF Test Development

- Robust full envelope expansion
  - *Excellent results*
- All terrain types
  - *Flat, moderate, mountainous*
  - *Low reflective (water / sand)*
- Adverse weather
- Full speed / aircraft weight range
- Interleaved radar modes
  - *Simultaneous RTF / SAR map / Air-to-Air tracks*

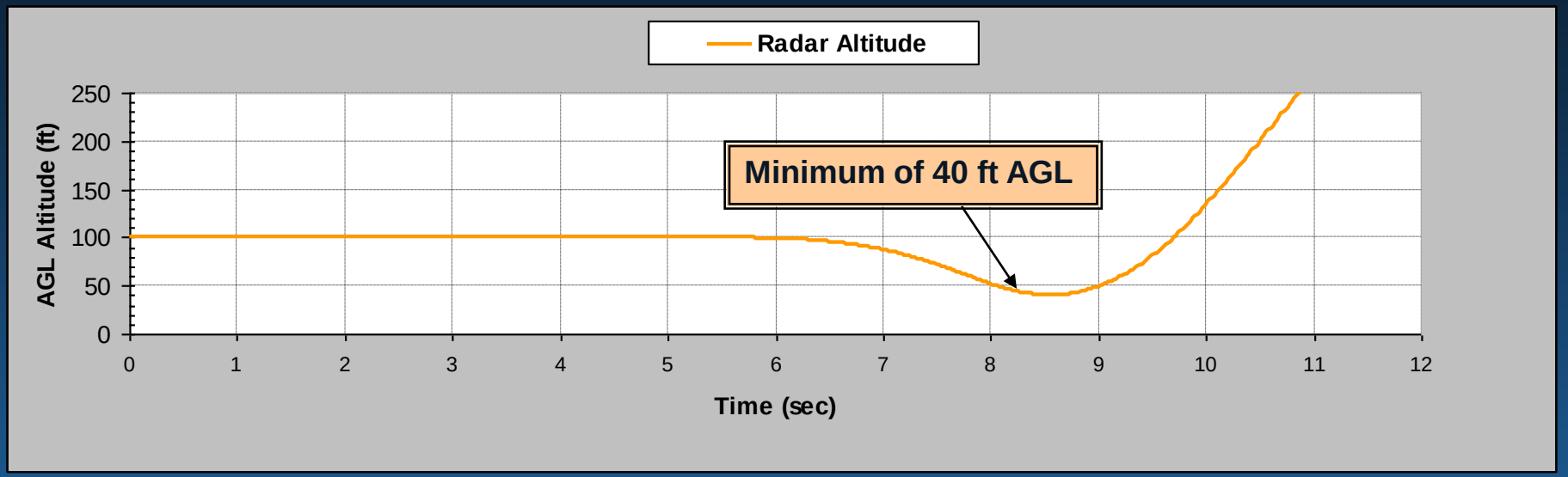
RTF Over Water Event

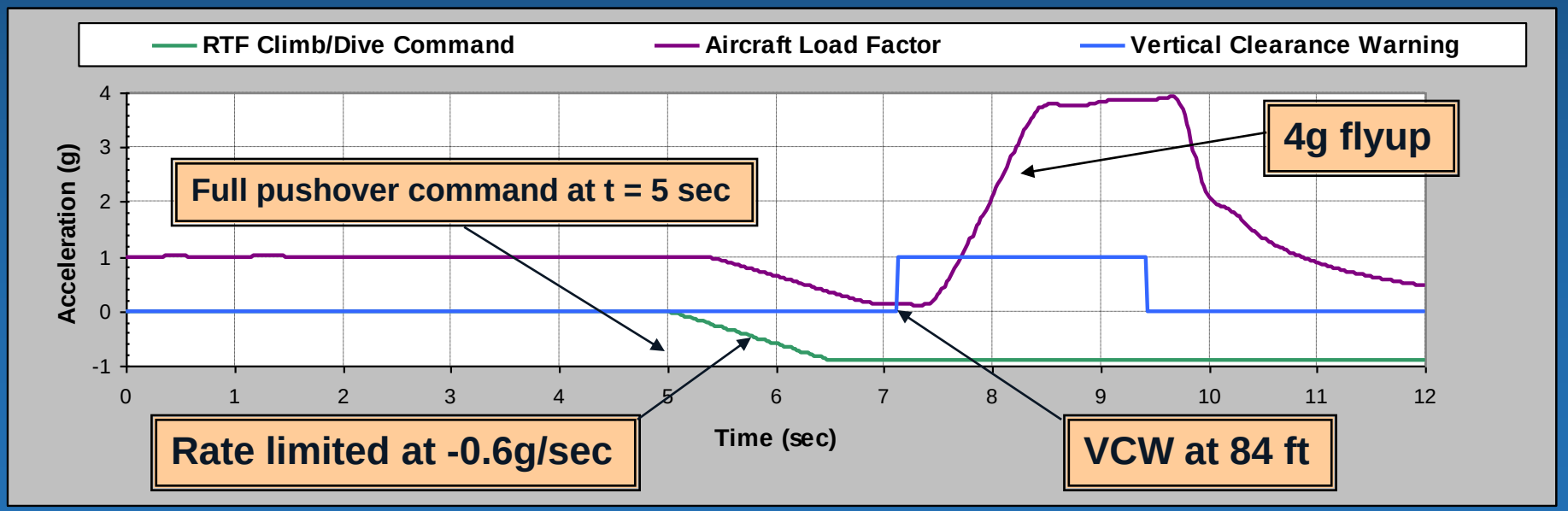
- Speed and altitude verification over water
  - *Near end of test program*
- Gulf of Mexico
  - *Perfect day*
  - *Calm water / no wind*
- Test Point
  - *Auto RTF*
  - *600 KCAS / 100 ft AGL / non-turning*
- Event
  - *Full Command -1 g pushover at 100 ft AGL*

RTF Over Water



Analysis - Automatic Ground Recovery





Causes and Solution

- **Logic anomaly in Radar software only evident under very limited conditions**
  - ***Few 'real' radar measurements***
    - Smooth water
    - Low grazing angle
  - ***Specific sequence required***
    - Last complete scan with no radar measurements
    - Current scan (in progress) with very few measurements at short range
  - ***Resultant RTF terrain profile contained erroneous height data***

- **Solution**
  - ***Ignore any 'no measurement' data from previous scan***
  - ***Use near-range radar measurements from current scan to create RTF terrain profile***

DBTF Test Development

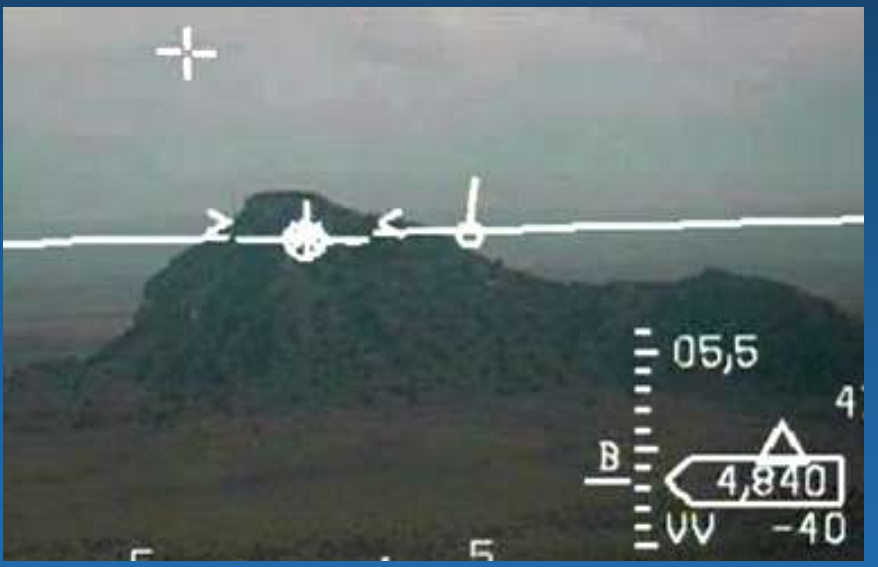
- **Robust full envelope expansion**
  - *Excellent results*
- **All terrain types**
  - *Flat, moderate, mountainous*
- **Full speed / aircraft weight range**
- **Good performance against vertical obstacles**

DBTF Twin Butte Testing

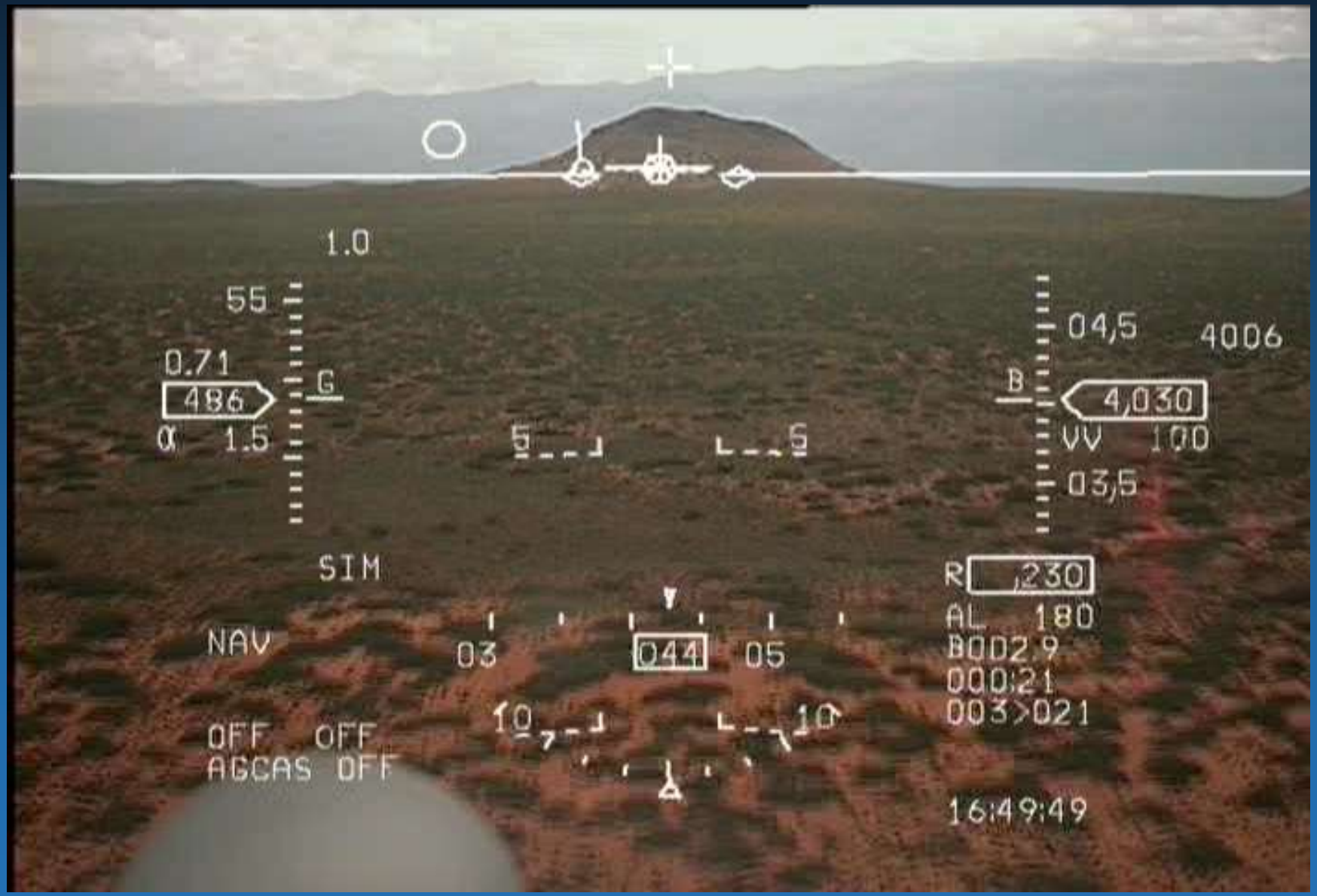
- **Rough and Moderate testing completed down to 200 ft AGL**
- **Flat terrain tested down to 100 ft AGL**

- **Test Point**
  - ***480 KCAS / 200 ft AGL / Auto***
  - ***Versus single vertical obstacle***

- **Event**
  - ***Fly-up over Butte when 75% of TCH incursion***

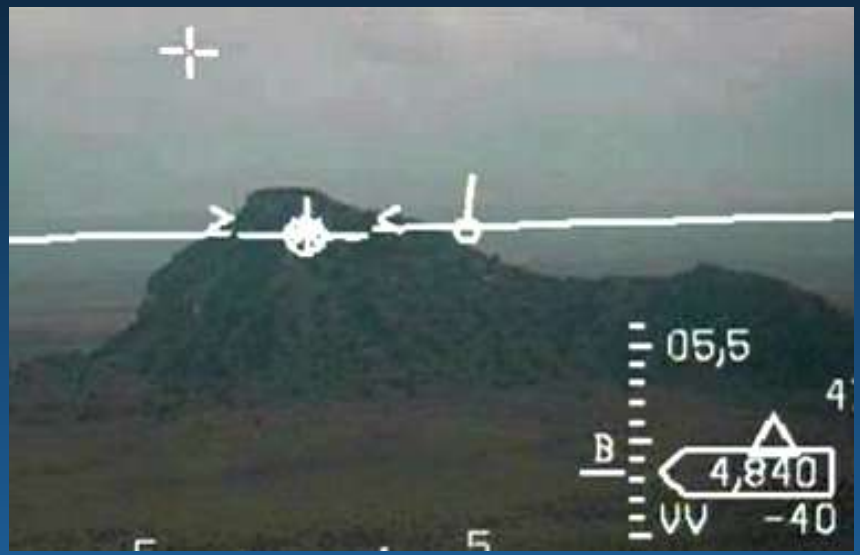


DBTF Twin Butte Testing

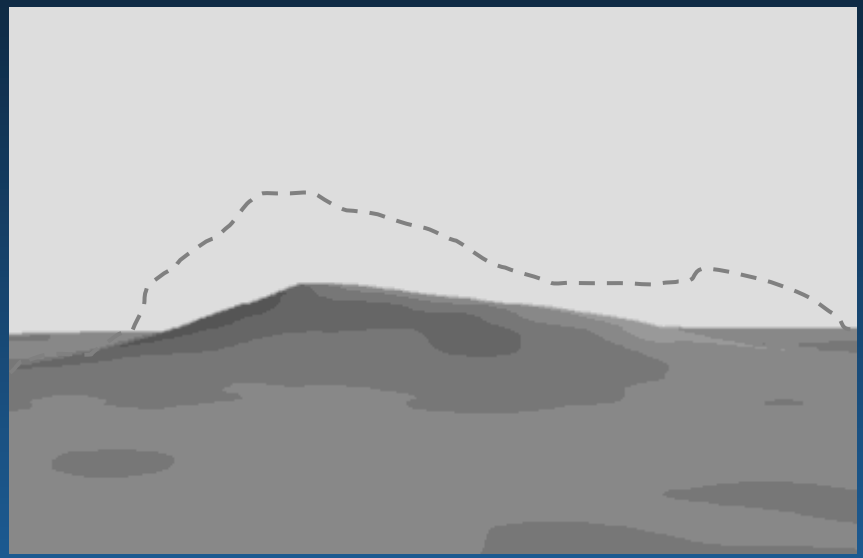


Legacy Level 1 DTED

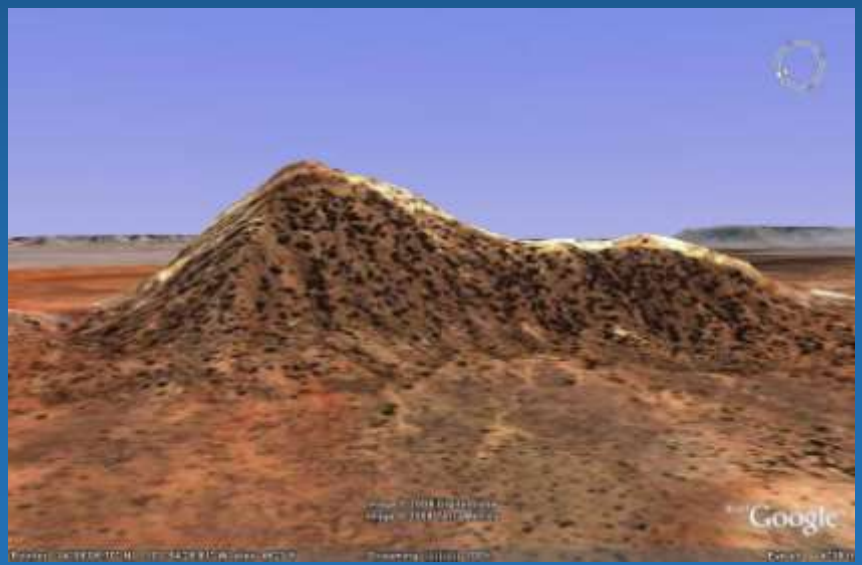
View from aircraft:



Legacy Level 1 DTED (rendered by Mission Planning System):

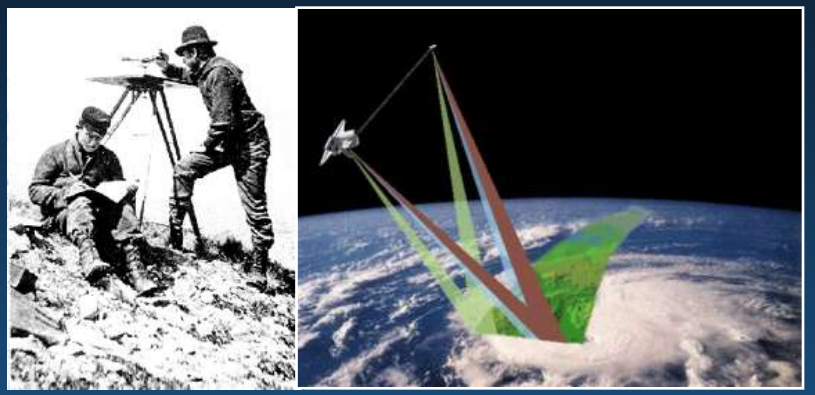


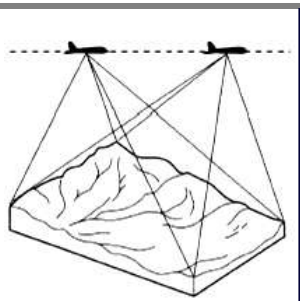
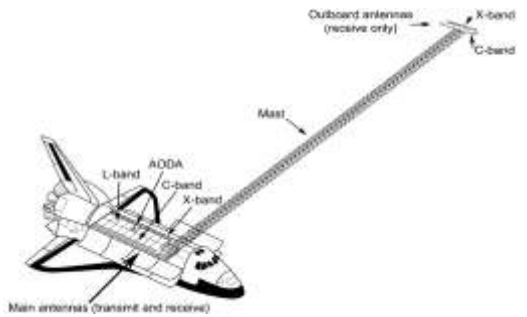
Google Earth:



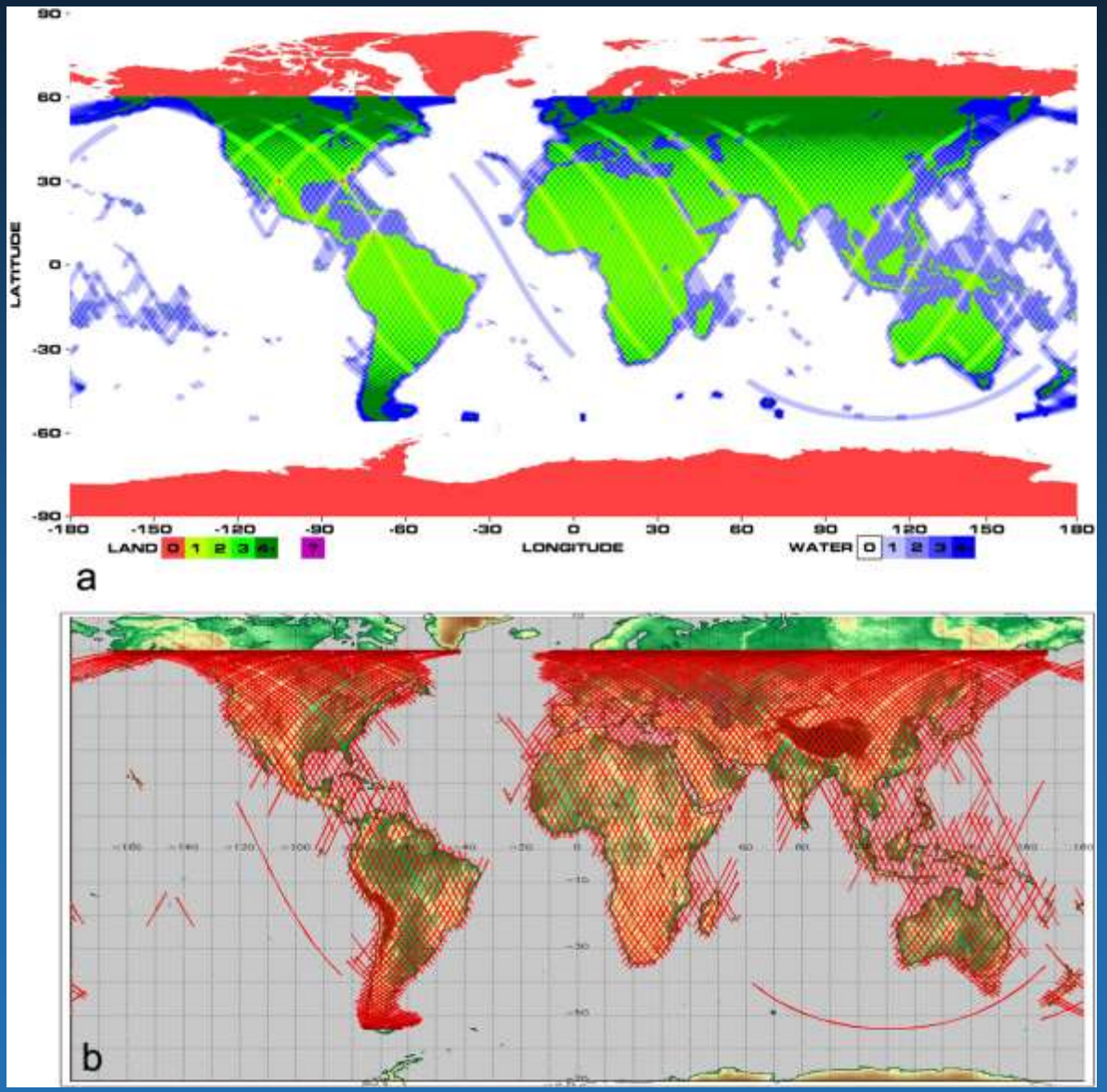
DTED Levels and Sources

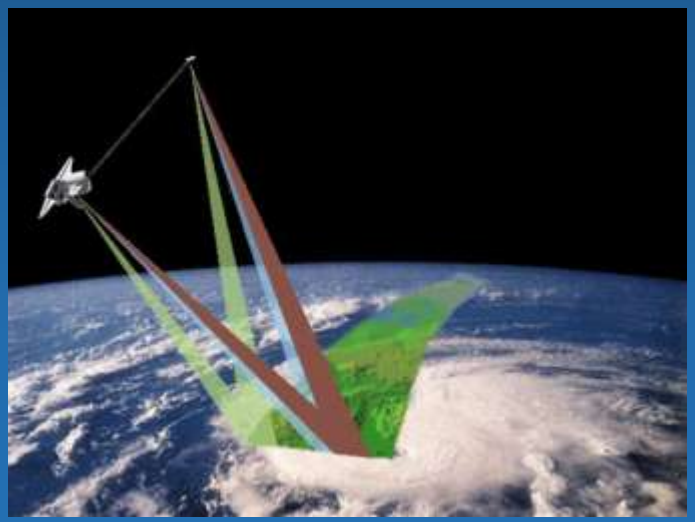
DTED Level	Post Spacing	Ground Distance
1	3 arc-sec	~300’ (100m)
2	1 arc-sec	~100’ (30m)



Source		Remarks
Legacy (Photogrammetric / Topographic)	 	• Coverage: – Level 1: ~70% of earth’s landmass – Level 2: ~ 10% of earth’s landmass • Issues: Non-homogenous, significant artifacts, “bare earth”
SRTM (Shuttle Radar Topography Mission – STS-99, Feb 2000)		• Coverage: 60 N to 56 S • Issues: – Not “bare earth” (some foliage and obstacles averaged in) – Voids where low reflectivity (sand, flat, water, extremely steep)

Shuttle Radar Topography Mission





Summary

- **Robust Terrain Following development**
  - ***All flight / terrain conditions***
  - ***Mature 'build-down' and envelope expansion procedures***
  - ***Rigorous test process***

- **Many other contributors to a test**
  - ***Perfectly calm water exposed faulty logic path***
  - ***Terrain data errors masked TF performance***

- **2 Incidents**
  - ***Saved by good luck or good test planning???***

Lessons Re-Learned

- **Never just testing a single discipline**
- **Spec Compliance is not necessarily Developmental Testing**
- **Development is a Discovery Process**
- **Diligence required until the end**

Questions ???