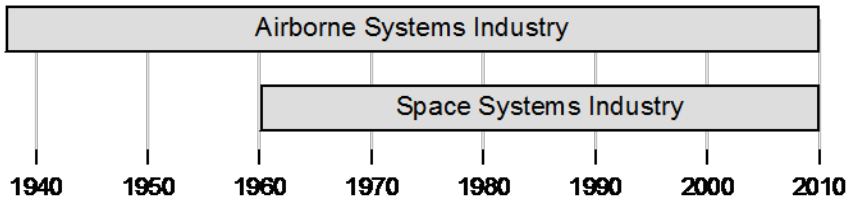
# The Migration of Payload Systems between Aviation and Space Platforms: SDRs as an Enabler

**Christopher Huffine**
**US Naval Research Lab**

**Stuart Nicholson**
**S. Nicholson Consulting**

# Historical Domain Isolation of Technology Utilization



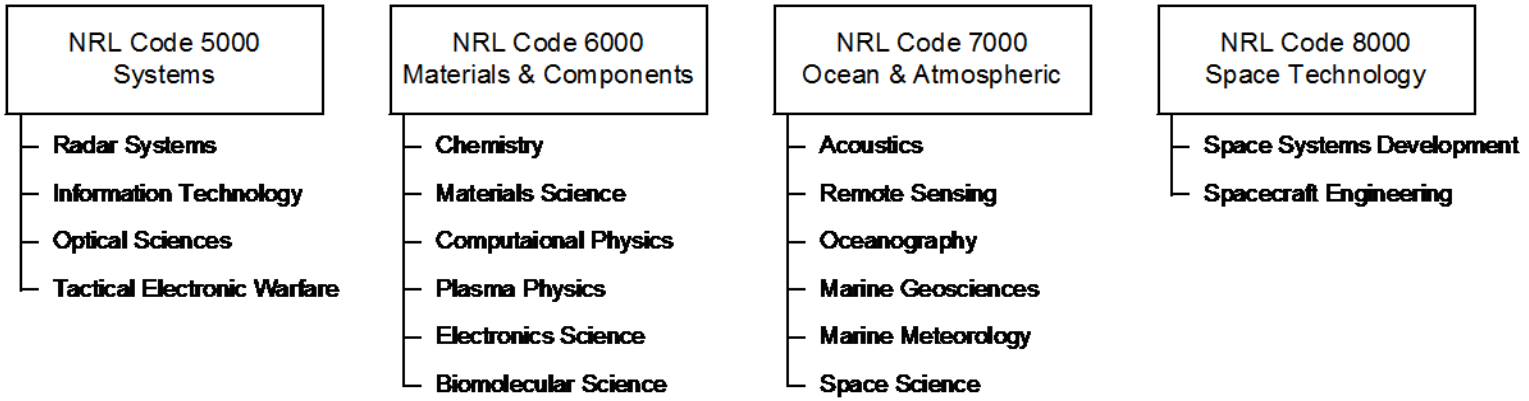

- Airborne systems industry well under way when Space started
  - Isolation due to vastly different host vehicle capabilities
- Airborne and Space domain isolation came with disadvantages:
  - Duplication of designs, higher manpower and costs
  - Less production volume, reduced utilization of a design resulting in fewer product refinement opportunities
- Restructuring of program security procedures in the 1990s assisted in cross-program knowledge and application
  - Still, large organizations, corporate and government, typically segregate their divisions by customer base, by application
- US Government has created programs and organizations specifically for encouraging cross-domain technology utilization:
  - TENCAP Office, MERIT Program, Others
- Competition for funding drives need to reduce costs of deploying new technology and fosters re-use of common design

# Cross-Domain Technology Utilization

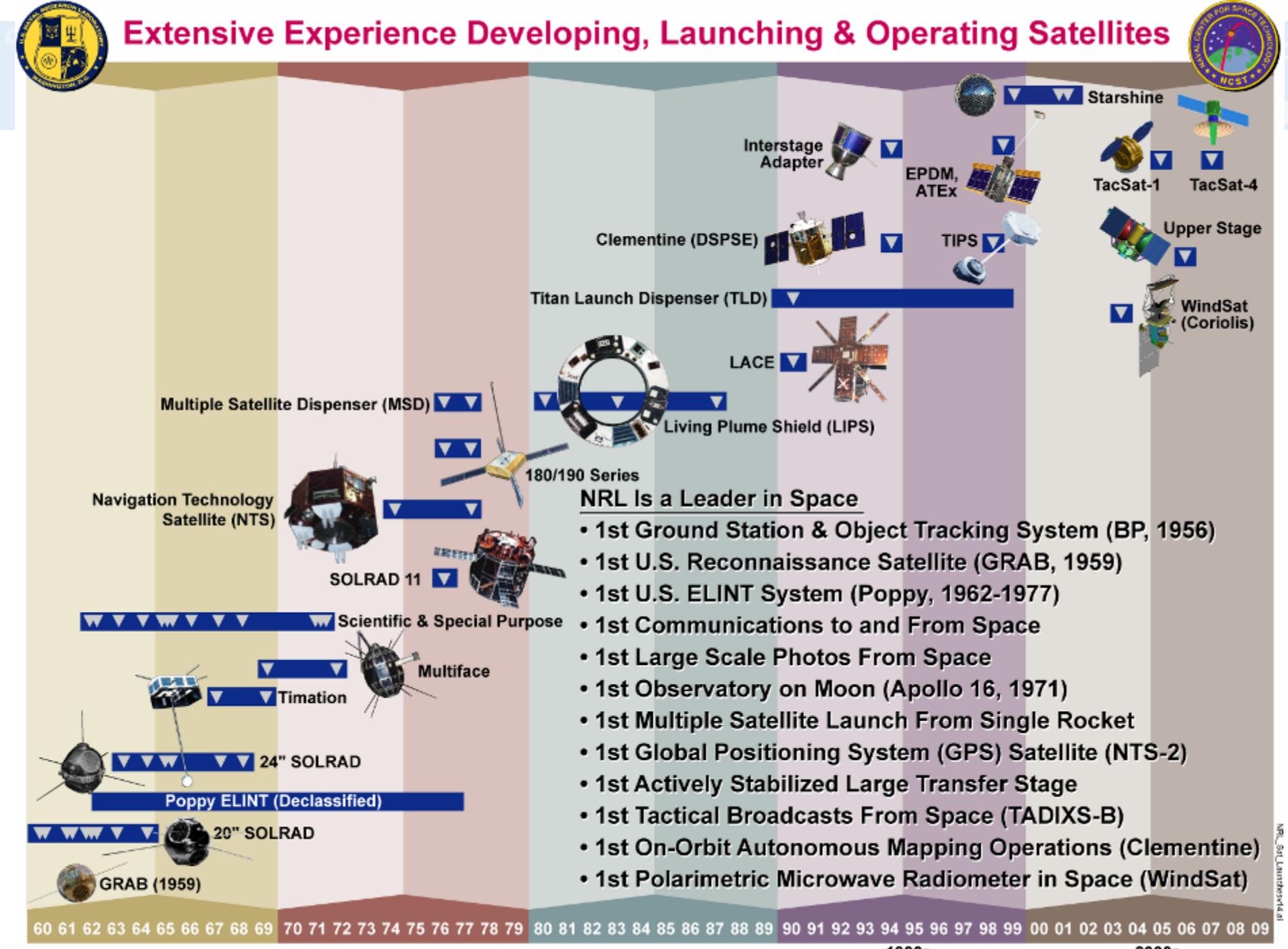
- **Benefits of cross-domain technology development and utilization:**
  - **Reduced development manpower, schedule, and cost**
  - **More utilization brings more refinement**
  - **Greater production quantity lowers procurement costs**
  - **Cross-domain utilization exposes alternate solution viewpoints**
  - **Design-for-cross-domain encourages generic, powerful solutions**
- **Cross-domain utilization can be accidental or intentional**
  - **"Accidental" utilization occurs when an existing technology is adapted to work in another application domain**
  - **"Intentional" utilization occurs when an existing technology is used in a domain which was specifically considered in its design.**
- **The Copperfield technology was developed for the airborne UAV environment, was adapted and extended for space use, then re-deployed in additional airborne applications**
- **The Software Reprogrammable Payload was derived from a space design but created for an airborne environment, with design characteristics and capability suitable for future space applications.**

# U.S. Naval Research Laboratory

- **The Naval Research Laboratory provides a unique environment to support those efforts with the broad multi-disciplinary approach across our divisions**
- **The huge diversity of programs and capabilities provides many opportunities for creating cross-domain technology**



# Extensive Experience Developing, Launching & Operating Satellites

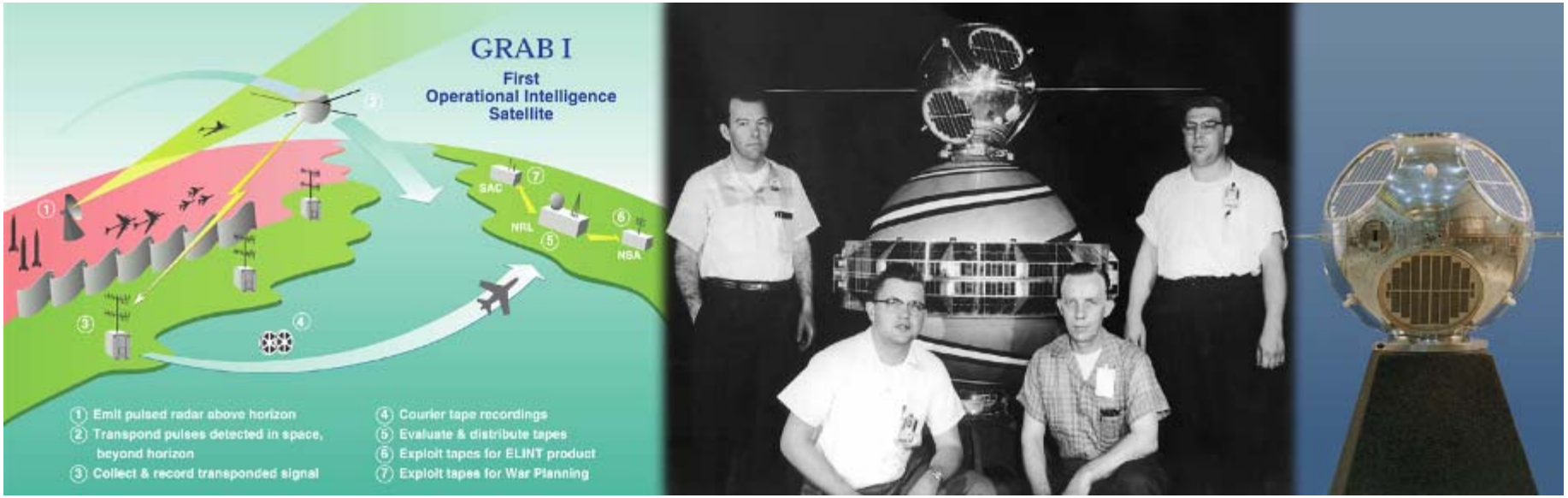



## NRL Is a Leader in Space

- 1st Ground Station & Object Tracking System (BP, 1956)
- 1st U.S. Reconnaissance Satellite (GRAB, 1959)
- 1st U.S. ELINT System (Poppy, 1962-1977)
- 1st Communications to and From Space
- 1st Large Scale Photos From Space
- 1st Observatory on Moon (Apollo 16, 1971)
- 1st Multiple Satellite Launch From Single Rocket
- 1st Global Positioning System (GPS) Satellite (NTS-2)
- 1st Actively Stabilized Large Transfer Stage
- 1st Tactical Broadcasts From Space (TADIXS-B)
- 1st On-Orbit Autonomous Mapping Operations (Clementine)
- 1st Polarimetric Microwave Radiometer in Space (WindSat)

NRL_Sat_Launches14.ai

# NRL's Galactic Radiation and Background (GRAB): United States' First Operational Reconnaissance Satellite



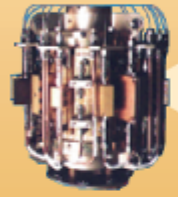

- **U.S. Navy Electronic Intelligence (ELINT) Satellite System Became Operational in July 1960 and Operated Until August 1962**
- **GRAB Carried an Unclassified Instrument to Measure Solar Radiation (SOLRAD)**
- **Covert Adjunct Mission Obtained Information on Soviet Radars Not Observed by USAF and Navy Ferret Aircraft**
- **NRL Proposed and Developed the GRAB Satellite and Its Network of Overseas Ground Collection Sites**

Declassified June 1998 on NRL's 75th Anniversary

# Cross-Platform Technologies

## On-Orbit Test & Demonstration of Advanced Technology

### High Temperature Superconductivity Space Experiment (HTSSE)



Development & Spacecraft Integration (14 Months)

### Clementine Deep Space Program Science Experiment (DSPSE)

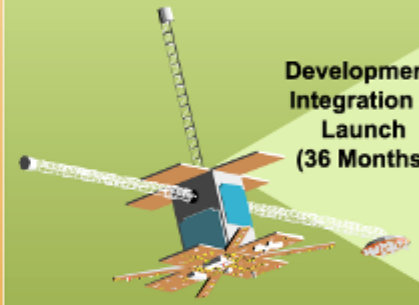
Concept to Launch (21 Months)

### TacSat-1 Experiment

Concept to Launch (12 Months)

## On-Orbit Testing

### Low Power Atmospheric Compensation Experiment (LACE) Space System



Development, Integration & Launch (36 Months)

### Tether Phyics & Survivability (TiPS) Experiment

Development, Integration & Launch (16 Months)

## Tactical Avionics Communications Systems

### Improved Data Modem (IDM)

Concept to Demonstration (9 Months)

### Multi-Mission Advanced Tactical Terminal (MATT)

Concept to Prototype (24 Months)

## Operational Comms System Proof-Of-Concept

### Living Plume Shield (LIPS)

Concept to Launch (6 Months)

### Integrated Communications System (ICS)

Development & Spacecraft Integration (11 Months)

DemoSuccess Rework.ai

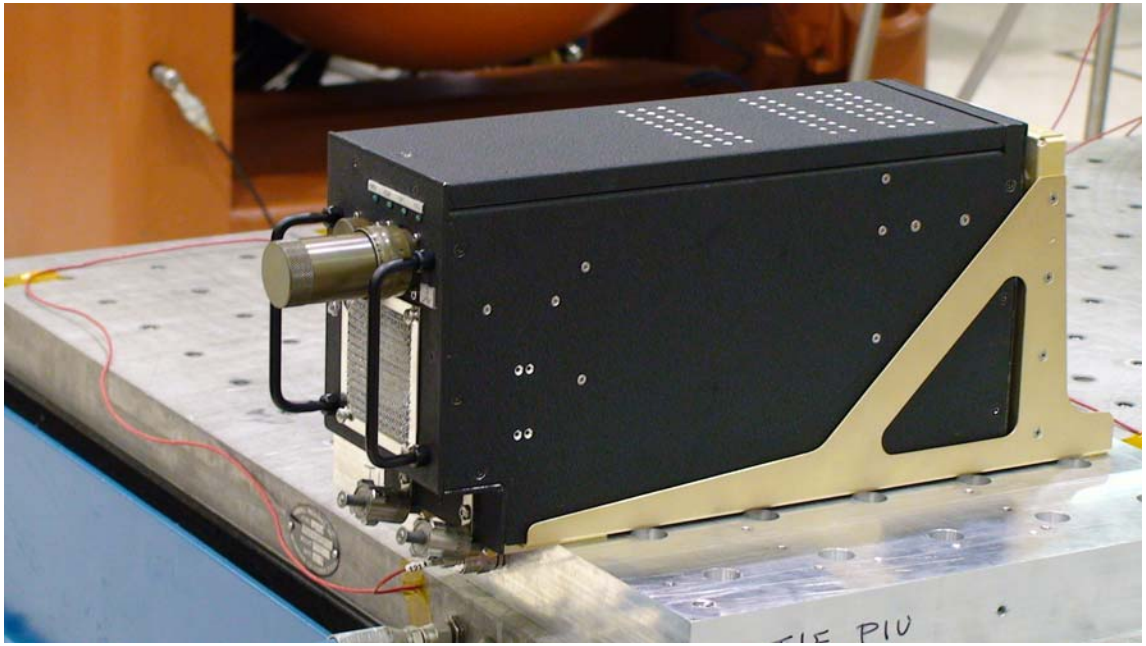
# Migration of Copperfield Technology Between Domains

- **Copperfield began as a radar signal interception pulse processor for UAV**
  - **Modularize RF processing, data processing, timing references, and networking**
  - **Maximize use of general purpose processors and open source Linux operating system**
  - **Incorporated extra serial, synchronous serial, and Ethernet interfaces for future growth**
- **Prepared for space use with suitable environmental packaging**
- **Added software-defined radio processing to 2nd space version**
- **Re-adapted the space SDR system for use on Global Hawk UAV**
- **Multiple uses made possible by variety of extra interfaces and excess processing capacity**

***Utilization of Copperfield Technology***

| Platform | Domain | Year |
|---|---|---|
| Predator class UAS | Aviation | 2001 |
| Firescout class UAS | Aviation | 2003 |
| TACSAT-1 | Spacecraft | 2004 |
| Tier-II UAS | Aviation | 2005-6 |
| TIE/TACSAT-2 | Spacecraft | 2006 |
| Subsurface | Subsurface | 2006-7 |
| GlobalHawk Class | Aviation | 2007 |
| MSS | Terrestrial | 2008 |
| TACSAT-1A | Spacecraft | 2008/9 |

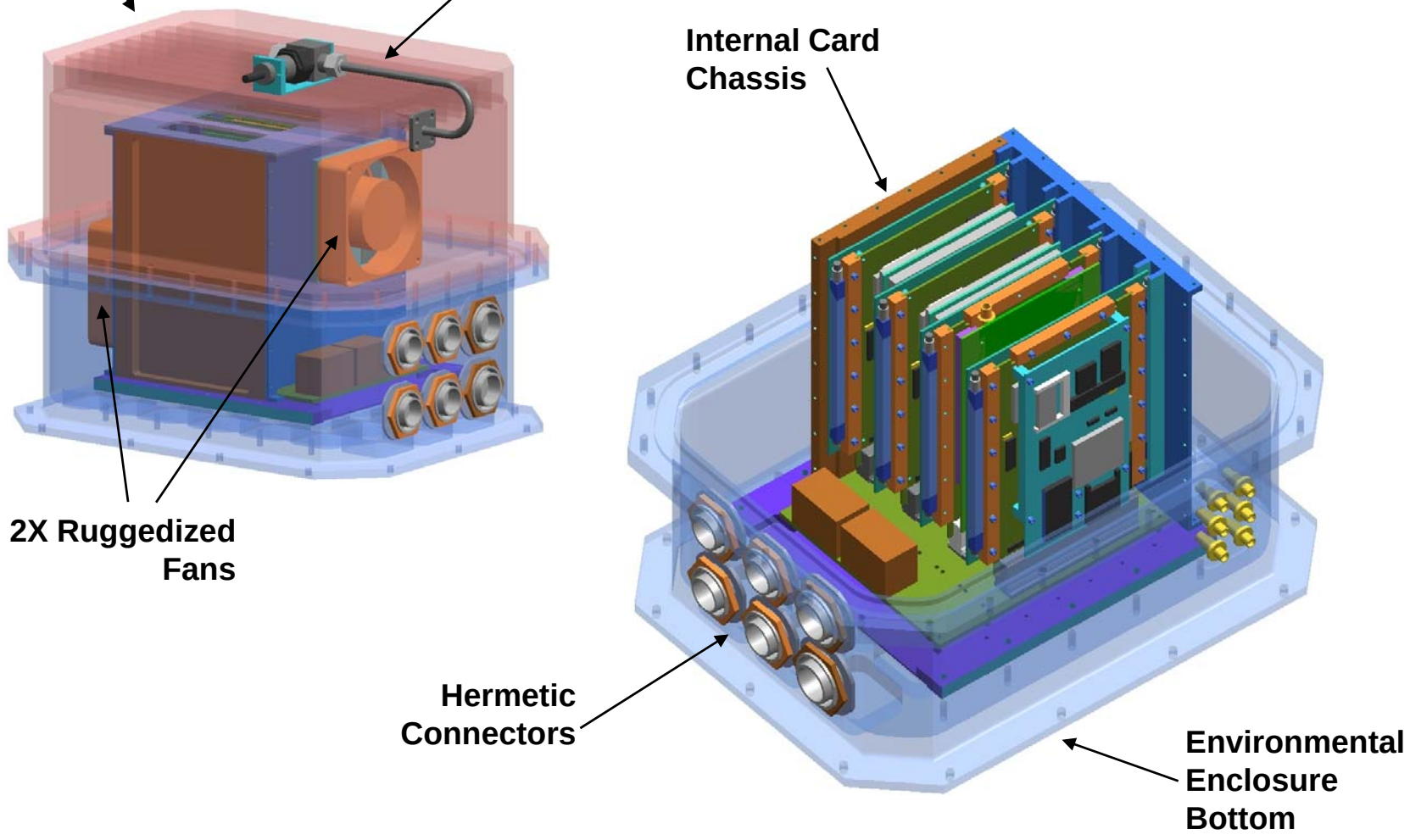
# Copperfield UAV System - Modular and Generic



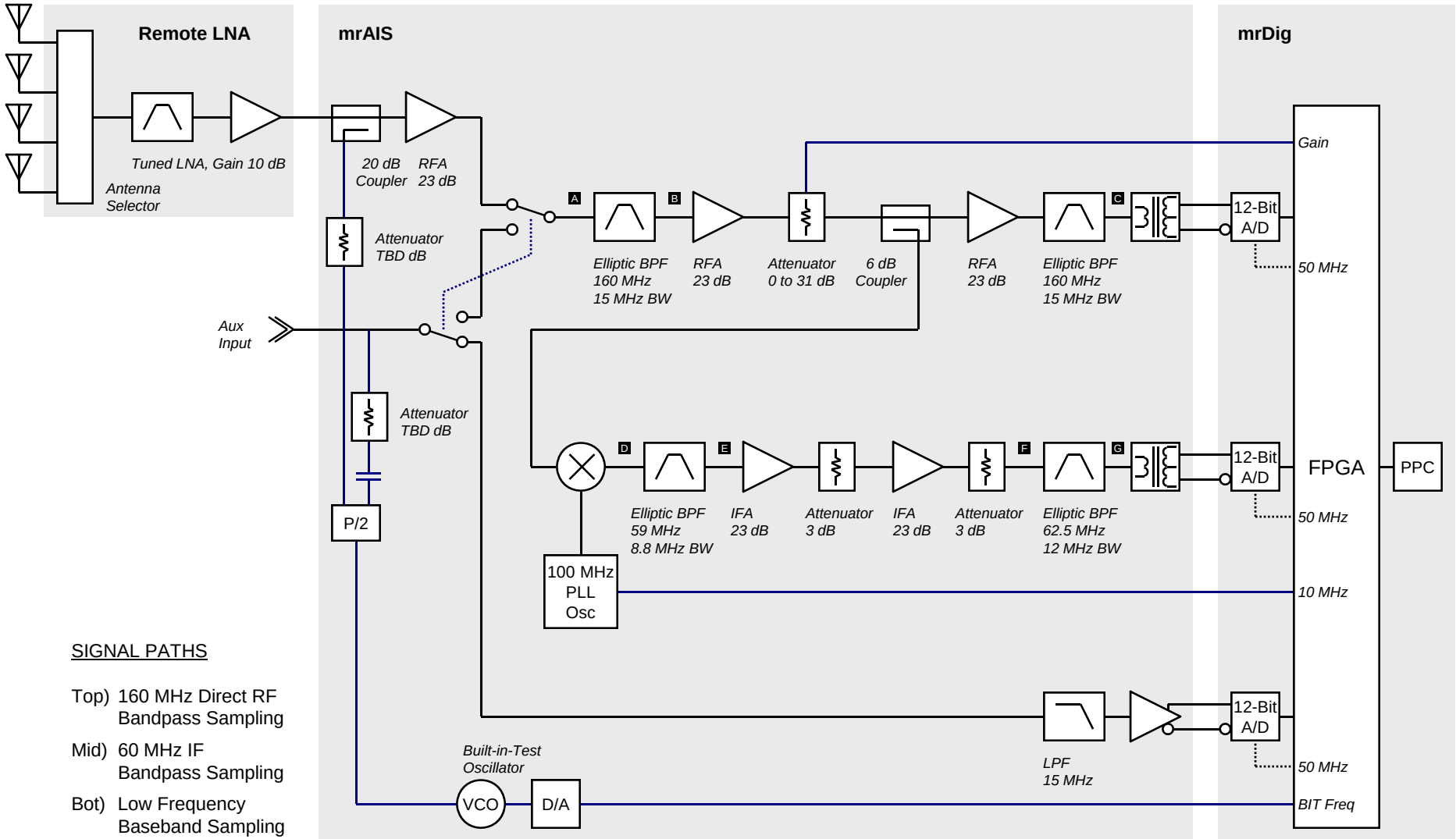
- **Modular Processor**
  - **General Purpose Processor - Running Linux**
  - **RF/IF daughtercard for radar pulse processing**
- **Modular Time & Frequency Reference - Running Linux**
- **Modular Network Communications**
- **Modular RF Electronics Control - Running Linux**

# Tacsat-1 and -2: Copperfield Goes to Space

| Size, Weight and Power | | | |
|---|---|---|---|
| | *Size* | *Weight* | *Power (Inside)* |
| TCU | 14.1 x 10.7 x 11.9 in | 30.9 Lb | 36 Watts |



# Tacsat-2: Copperfield Becomes Software-Defined Radio




SIGNAL PATHS

Top) 160 MHz Direct RF Bandpass Sampling

Mid) 60 MHz IF Bandpass Sampling

Bot) Low Frequency Baseband Sampling

# Copperfield: Serendipity and Ingenuity

- GPP Processor baseboard with RF/IF interface daughterboard
  - Initially used with IF radar pulse processing board and data handling and control/status in GPP.
  - New RF daughterboard for VHF Marine, all new FPGA firmware for software-defined-radio channel filtering and signal correlation, new GPP software for signal demodulation.
- FPGA and GPP software further modified to stream continuously-sampled IQ data stream.
- Tacsat command/telemetry capability included ability to upload and execute GPP shell scripts.
  - Worked around ground station behavior so that sets of commands were kept “atomic”, with multiple commands in single “tarfile”.
  - Allowed for reformatting of flash drive on several occasions.
- Experience with Copperfield modularity and designs implemented in FPGA firmware and GPP software encouraged cross-domain-by-design
  - The Software Reconfigurable Payload implemented with even more interfaces and modularity than Copperfield
  - The SRP design specifically targets cross-domain application

# Difficulties with Cross-Domain Design

- Latest technology parts often not suitable for space environment
  - High device density can yield susceptibility to single-event-upset
  - RF components are often acceptably hard though
  - Passive components rarely present problems in space design
- Radiation-hardened general-purpose processors are older technology
  - Think outside the box: expect and plan for SEU (be careful of SEB !)
  - In some applications, SEUs are equivalent to noise: lower S/N ratio
- Semiconductor product lifetimes are very short, especially compared with spacecraft development, test, launch, operate timelines
  - Buy early, buy extra, expect end-of-life final buys
- Traditional purchasing to customer's Source Control Drawings of limited interest to standard-product semiconductor manufacturers
  - Except for custom semiconductor foundries
- Limited production volume
  - Sometimes latest technology unavailable for low-volume applications - can't even get spec sheets in some cases
  - Multi-domain application increases product volume, but airborne and spacecraft markets are still comparatively low-volume

# Planning for Cross-Domain Application

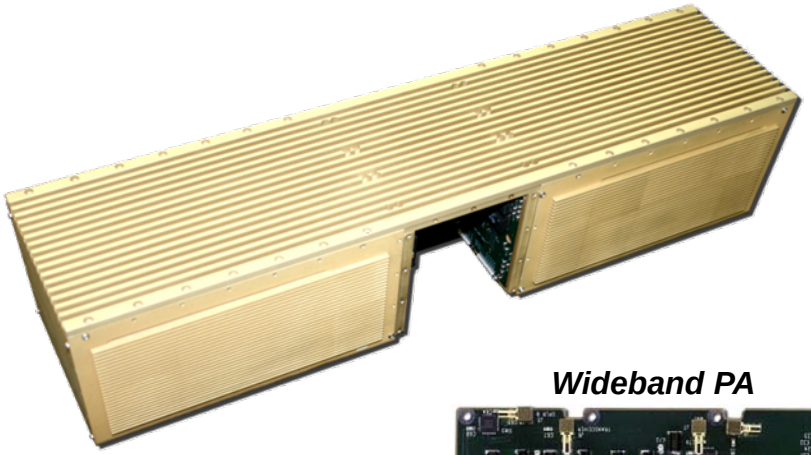
- The goal of designing for cross-domain application is to:
  - Design components which can be employed in both airborne and space environments with little or no adaptation
- The benefits which accrue to cross-domain design include:
  - Reduced costs by re-using previous generic, high-capability designs
  - Reduced costs through higher production volume
  - More schedule responsiveness because of reduced development effort
  - Improved product quality from broader application base so that fixes and improvements are available to multiple projects
  - Lower cost for long term support due to common software infrastructure
- Methods to create cross-domain applicability include:
  - Creating broadly-applicable, generic external interfaces
  - Providing various types of spare interfaces for future application
  - Using generic processors and operating systems with large excess capacity
  - Designing in large FPGA devices, higher speed processors, extra memory since costs are dominated by engineering efforts and not component cost
- Look across upcoming projects, applications, and technologies and strive to address those foreseeable needs now

# SRP - Planning for Cross-Domain Application

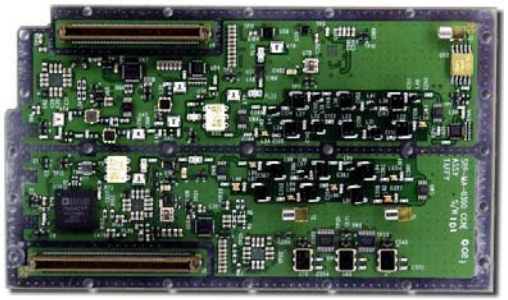
- The Software Reconfigurable Payload design:
  - Descends from the RF/Digital Payload developed for the Operationally Responsive Space office
    - RDP - a space-qualified Software-Defined Radio (SDR) platform
  - Leverages the experiences in cross-domain application gained from the Copperfield system and component application
- Envisioning cross-domain applications, the SRP:
  - Incorporates the fastest Freescale PPC processors which were successfully used in the Tacsat-2/TIE project
  - Includes the largest available FPGA devices
  - Provides an in-FPGA routing fabric and SDR component library
  - Utilizes upgradeable RF/analog daughter cards with high-speed interfaces directly to the FPGA component
  - Provides numerous interface types, including multiple serial, USB, Ethernet, sound, digital, cPCI, and PCI-Express
  - Utilizes the latest 2.6.33 Linux kernel for its GPP software base
  - Provides an integral timing and position GPS infrastructure
  - Allows operation with multiple processor/receiver boards
  - Provides large on-board flash storage

# SRP Modular Components

***8 Module Chassis***

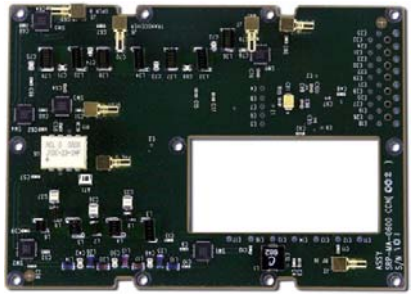


***Wideband RF***



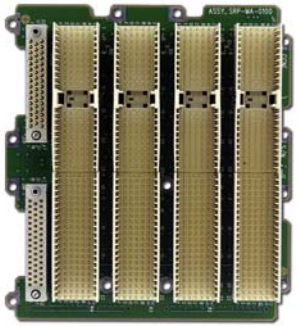
***Narrowband RF***

***Wideband PA***



***Processor***

**Backplane**



***GPS/Clock***

***Narrowband PA***

# Cross-Domain Payload Migration: Economic Efficiency

- **The Software Reconfigurable Payload presents our best effort-to-date at planning for future application in both airborne and space environments**
- **The software-defined-radio application demands a large range of capabilities to accommodate future waveforms**
- **We expect to achieve:**
  - **Extensive application to state-of-the-art radio data waveforms**
  - **Success implementing unknown applications in and out of the software-defined radio arena**
  - **Broad re-use of the SRP technology for several years to come**
  - **Greater insight into how and why to develop cost-effective, wide re-use technology**
- **Key to cross-domain application is preparing for the unknown and understanding other's technology, to imagine new and alternative uses for that technology**