Electronic Data Sheets at ESA: Current Status and Roadmap

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December 2017

Sentinel-2 In-flight Anomaly

- **First day after launch report star trackers misaligned**
  - STR1 with STR2: 0.83 deg, STR1 with STR3: 1.1 deg, STR2 with STR3: 0.4 deg
  - Reported stable, no impact in Initial Acquisition Mode, not foreseen impact in Orbit Control Mode
- **Root cause: incorrect transformation matrix being used between Boresight Reference Frame and Alignment Reference Frame (transposed matrix shall have been used)**
  - The matrix was nearly symmetrical and mistake was not spotted
  - Wrong interpretation of ICD information

- **Sentinel-2A lessons learned: Dedicated thorough check of all configurations recommended**
  - Similar mishaps reported in other satellites
  - Taken very seriously by project and industry in before Sentinel-2B launch
  - Additional rigorous check of all configurations and calibrations implemented shortly before Sentinel-2B launch
- **Sentinel-2B in flight:**
  - Measured MIMU misalignment due to "matrix wrongly interpreted wrt direction of transformation"
  - STR quaternion not normalized due to wrong assumption (misalignment few µrads)

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ALL OF THIS WOULD BE AVOIDED

IF ICD WAS UNAMBIGUOUS

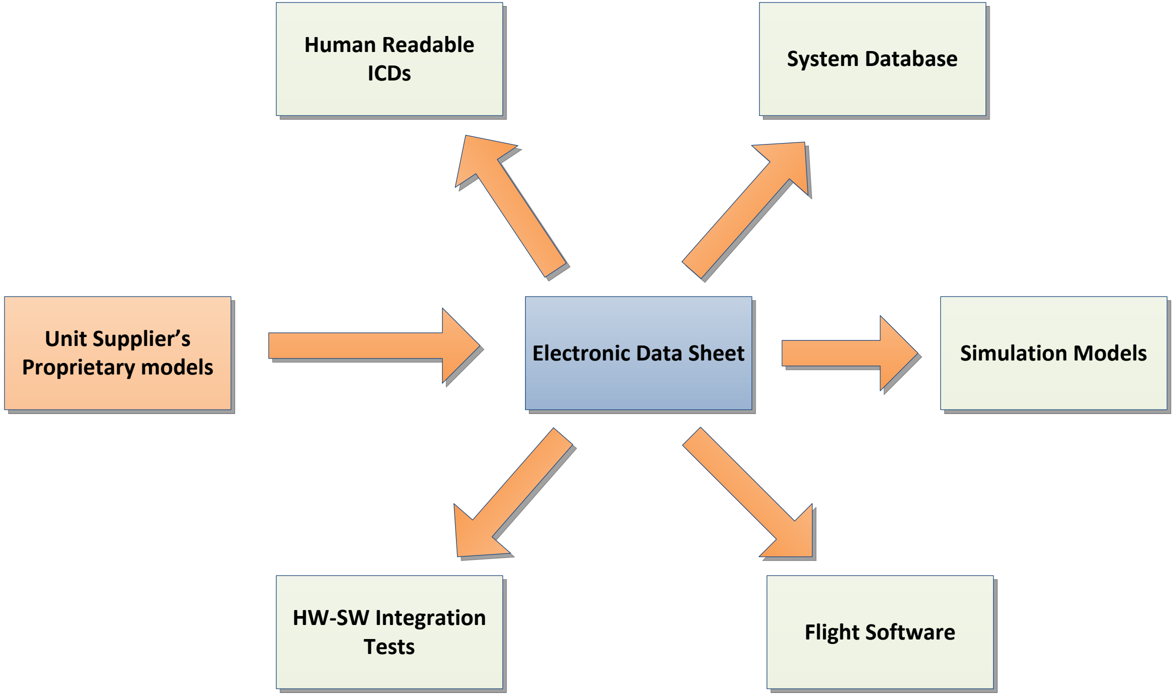
AND USED CORRECTLY

Electronic Data Sheets (EDS) – What is it?

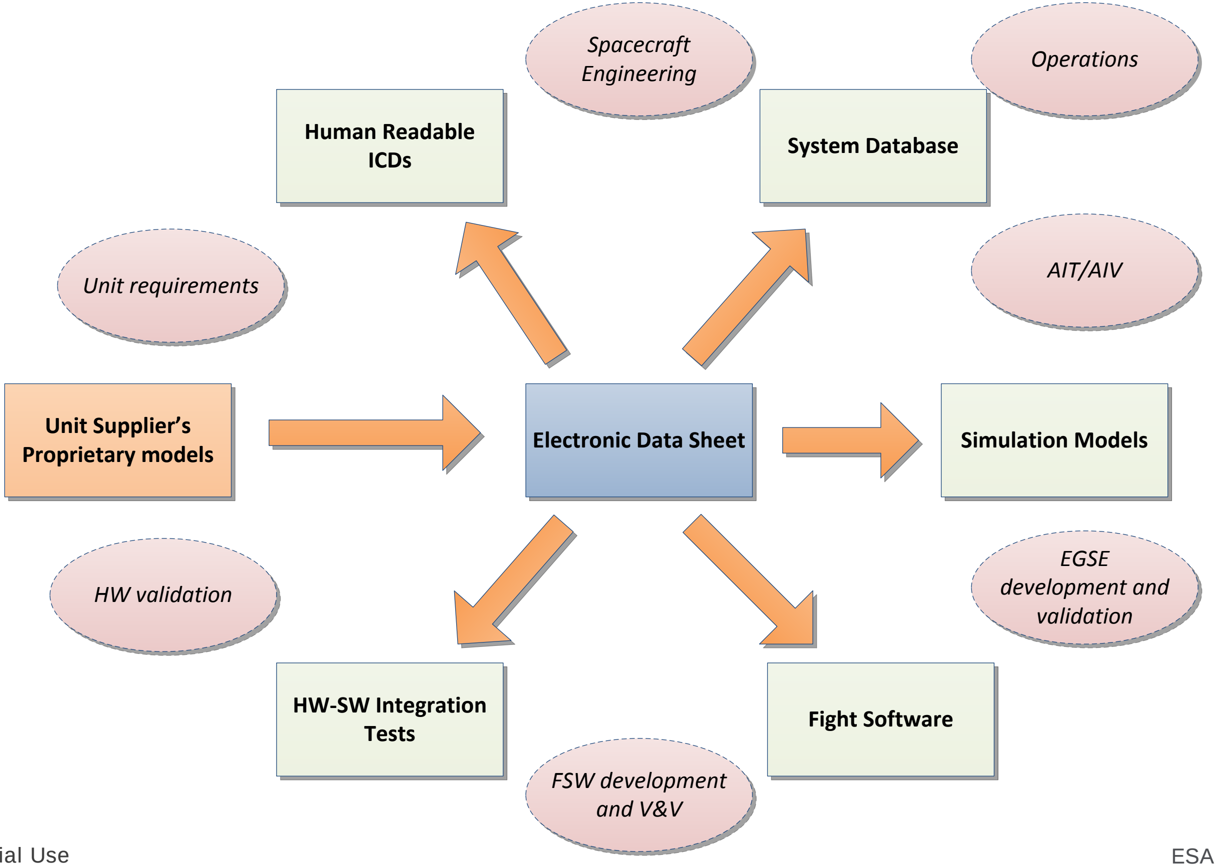
- **Machine-readable mechanism to describe data interfaces of electronic units onboard spacecraft**
  - Sensors, actuators
  - Other units (PCDU, RIU, Solid State Mass Memory)
  - Instruments

- **Objective: Replace paper ICDs and data sheets which accompany each device and are necessary to determine the device operation and how to communicate with it**
  - Initially functional/data handling (i.e. TM/TC ICD)
  - But gradually also electrical, thermal, mechanical

Electronic Data Sheets – Use Cases



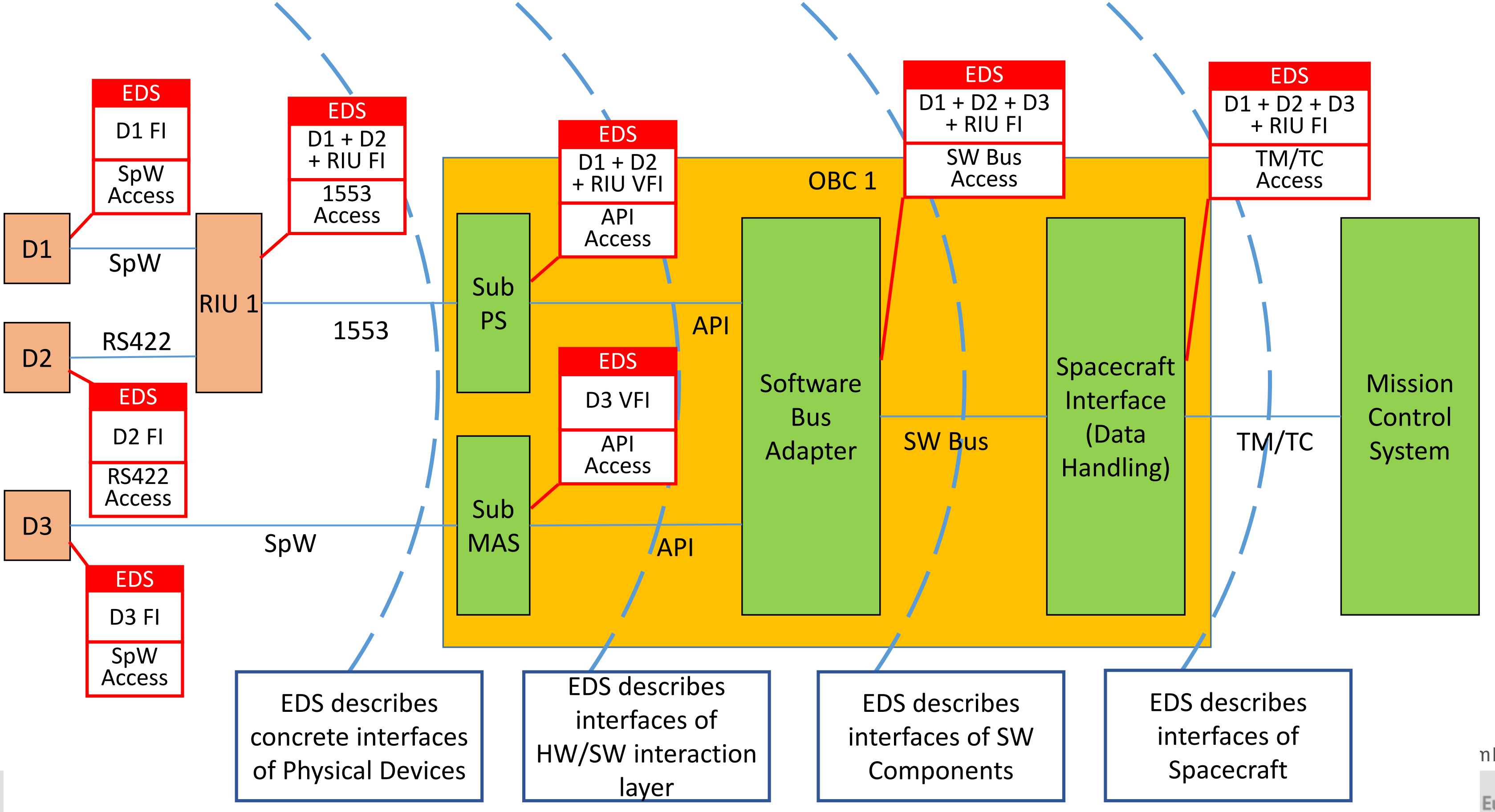
Electronic Data Sheets – Multiple Domains



CCSDS SOIS EDS (SEDS) Overview

- **XML Schema**
  - Based on Red Book CCSDS 876.0-R-2
  - ~276 requirements on SEDS schema elements
  - XML schema provided
  - 3 main elements: Data Type, Interface Type, Component Type
    - Types, Interfaces, Parameters, TM/TC Packets, State machines
  - Organised and grouped inside Namespace elements
- **Dictionary of Terms (DoT)**
  - Based on Red Book CCSDS 876.1-R-2
  - Vocabulary to annotate data interfaces in Electronic Data Sheets
  - It contains the ontology of the types used in the EDS
    - Standard DoT vs. User-Defined DoT

Electronic Data Sheets – System View



Electronic Data Sheets – Status Today

- **ESA conducted several studies in 2013-2016**
  - Understanding requirements, process, tools, format, use, semantics
    - Contributing to CCSDS XML Spec for EDS
    - Initial focus mostly on FSW generation and data handling
    - Focus on SOIS reference architecture (Device Access Service, Device Virtualization Service)
  - EDS of several avionics units (developed with the help of unit suppliers)
    - Jena Optronics Astro APS star tracker
    - Sodern Hydra star tracker
    - TAS UK MEMS Rate Sensor (MRS)/SiREUS
    - FOG Astrix 120 Gyro
    - NPAL Camera

Electronic Data Sheets – Status Today

- **(continuation)**
  - Improving ESA's reference EDS tool chain
    - EDS validation
    - FSW code generation (C language)
    - HTML generation
  - EDS verification using communication log produced by real HW
    - Checking telecommands and telemetry, checking protocol using state machines
  - Using the star tracker EDS with the star tracker simulator
    - Checking commands, checking responses, injecting commands
  - Automatically generating HTML documentation
    - Human readable ICD
    - Test report against EDS, including TM/TC coverage

Electronic Data Sheets – Status Today

- **Standardization in CCSDS with other agencies (NASA primarily)**
  - **End of 2016: Finished second agency review of two EDS books**
    - XML Specification for Electronic Data Sheets for Onboard Devices and Software Components (876.0)
    - Specification for Dictionary of Terms for Electronic Data Sheets for Onboard Components (876.1)
  - **CCSDS plan for 2017-2018**
    - Updating "Electronic Data Sheets and Common Dictionary of Terms - Overview and Rationale" Green Book (870.1)
    - Prototyping tool chains
    - Interoperability tests
      - Interoperability test plan
      - Two interoperable prototypes (ESA and NASA toolchain)
      - Mimicking scenario of NASA instrument onboard ESA satellite, interface defined in EDS (e.g. ESA JUICE mission to icy moons of Jupiter with NASA UVS instrument)

Electronic Data Sheets – Roadmap

- **Starting “SAVOIR Electronic Data Sheet Definition” activity**
    - Planned Kick Off end of 2017/beginning of 2018
    - Planned with heavy involvement of ESA Primes
    - Broader system-level view
    - User requirements, reference process
    - Focused primarily on Data Handling and Electrical ICD
    - SAVOIR EDS Data Model definition
    - SAVOIR EDS Common Toolset development
    - A number of use cases and prototypes
        - Generation of engineering/V&V/simulation artefacts
    - Feedback to standardization (CCSDS)

Looking 10 Years Back: Software Crisis

- **Mid 2000s: “European Space Software Crisis”**
  - Explosion of flight software complexity (cf. NASA FSW Complexity Report 2009)
  - Ad hoc fault management (cf. NASA Fault Management Workshop 2008)
  - Underestimating system impact of software
  - Flight software development driving schedules of missions (late change, delays)
- **Proposed solutions (in various ESA reports 2004-2009)**
  - New system and software engineering methods
  - Early modelling, simulation and prototyping
  - Code generation, test generation
  - Standardisation
  - Incremental development
  - Reuse
  - Tools allowing all this

Looking 10 Years Back: Is FSW Crisis Over?

- **Today: Solutions proposed above seem to work (kind of)**
  - Early FSW validation on software-in-the-loop simulators (HW emulation of onboard computer) and HW-in-the loop simulators
  - Incremental development (early FSW versions released to support spacecraft testing)
  - Software frameworks
    - To facilitate reuse (heavy reuse via product lines)
    - To facilitate “variability factors” (different avionics, comms bus, CPU, mission tailored requirements)
  - Modelling, code generation (mostly GNC)
  - Evolution towards Integrated Modular Avionics (IMA) and integration of software functions with different criticality
  - Standardisation (Independent SW V&V Guide, Packet Utilization Standard (PUS), Onboard Control Procedures (OBCP), Generic specifications (SAVOIR initiative), SMP2 standard for simulators, Improved ECSS standards)
- **EDS going further in this direction:**
  - **Modelling, artefact generation, model consistency, digital engineering**

Will EDS succeed? When? Why?

- **It is feasible!!!**
  - Simple “semi-formal” models, model transformations
  - The key thing is to standardize (contents and format)
  - … but not everything!

    FSW framework proprietary

    SRDB proprietary

    Tools as well!
- **Increasing interest in industry**
  - Making life easier (automatic flow of engineering data, inherent consistency, data validation)
  - Saving time/money/resources by reusing engineering data
  - Technology is available to do this
  - Evolution towards Digital spacecraft engineering is ongoing

Gathering Momentum

- **Different parts of ESA interested**
  - E.g. SIMULUS operations simulator models derived from EDS
  - Possibility to use EDS for programmable RIU
  - Possible use in early Concurrent Design Facility studies
- **International partners interested**
  - NASA, CNSA, CNES, DLR, …
  - Provides a great tool for interoperability (within the same spacecraft, spacecraft to spacecraft, system of multiple spacecraft)
    - Interfaces described in standardised machine understandable unambiguous format
    - Proprietary tools available to support system engineering on both sides without necessity to use the same architecture/standards (e.g. ESA's PUS encoded in EDS)
- **We need unit suppliers to get involved even more**
  - Making life easier (unambiguous ICD)
  - Such models already exist today but they are proprietary
  - Competitive advantage (provide units accompanied with standardized electronic ICDs)

THANK YOU

Questions?

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Backup Slide: Looking 10 Years Ahead

- **A lot of algorithms and applications on FPGAs**
  - Missing ECSS engineering standard

- **Integrated Modular Avionics**
- **Multicores (ESA's presentation at FSW'15)**

- **Agile software development**

- **Machine learning**
  - AI augmented GNC
  - Pattern recognition
  - Intelligent mission planning