An Example for Demonstrating Systems Level TRL

Outline

- Define the Proposed Subsystem
- Determine the Existing TRL
- Assess the Subsystem TRL
- Component Path to TRL 6
- Subsystem Path to TRL 6

Define the Subsystem

- An Attitude Determination and Control System for a 6U cubesat is being proposed
  - Two control modes are identified: initial de-tumbling and operations.
    - For the science operations, the ADCS Subsystem will provide control of the nadir vector to 1° with a knowledge of 0.5°
  - The cubesat will operate in LEO for 24 months
- The ADCS is based on a similar system this team used on a 3U cubesat
  - The previous 3U system constitutes the flight heritage for the ADCS. It contained:
    1) Magnetometer (senses vector geomagnetic field)
    2) Magnetic torquers (exert desired control torques)
    3) A Processor (receives geodetic coordinates from bus)
    4) Software (includes geomagnetic model)
  - The control modes were the same but the requirements were looser; control to 5° and knowledge of 2°
  - The cubesat operated for 90 days in LEO
- The following differences are identified:
  - A bias reaction wheel assembly (RWA) is needed to implement the tighter pointing control that introduces new hardware/software to the heritage architecture
  - The increased lifetime introduces a higher radiation environment than the heritage
- The ADCS simulation/software model from the 3U cubesat is augmented to reflect the proposed configuration with best estimates of the component performance and new algorithms.

From NASA Systems Engineering Handbook (SP-2016-6105 Rev2)

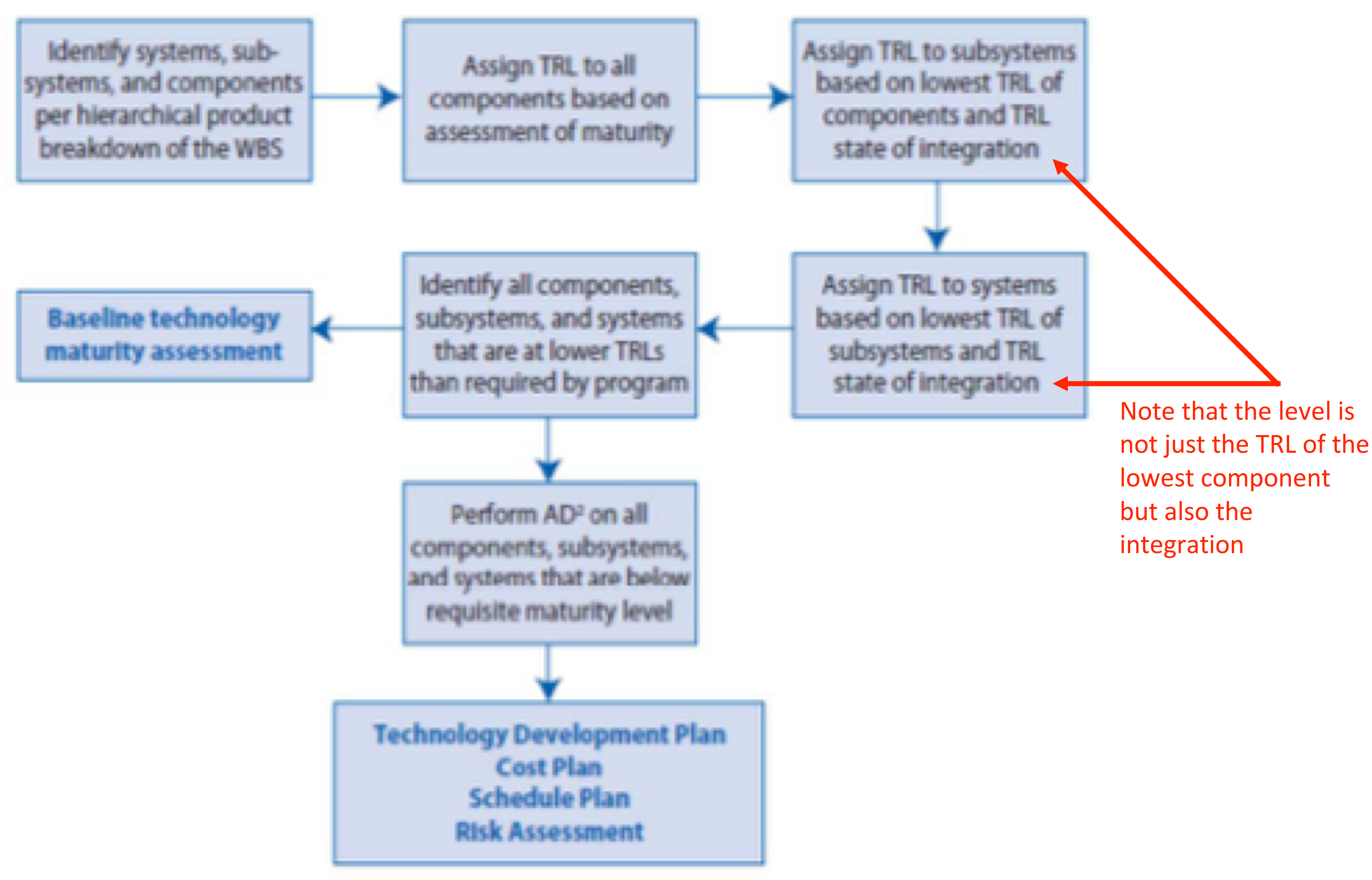

Figure G.3-1 Technology Assessment Process

Determine the Existing TRL

- Assign a TRL to each of the components
  - Magnetometer (TRL 9) - although the previous mission was only 90 days, the unit is COTS with demonstrated LEO heritage of sufficient duration on other missions. Meets required accuracy
  - Magnetic Torquers (TRL 5) - The units used on the 3U cubesat are too small to handle the increased mass and lifetime was too short. Units need to be scaled up to provide control and RWA desaturation. Parts are evaluated for radiation exposure and mechanical environments (vibe/shock)
  - Processor (TRL 9) - Similar to the magnetometer, the COTS unit had excess capability for the previous mission and can accommodate the new algorithms to support the RWA control. Has demonstrated LEO heritage of sufficient duration and radiation exposure on other missions.
  - RWA (TRL 6) - After examining available COTS RWAs, a suitable COTS unit is found that is under development but hasn't flown yet. Successful performance testing of an engineering model has been performed in the laboratory along with accelerated life testing. Radiation exposure has been evaluated and all parts meet the radiation requirement.
  - Software (TRL 5) - New (to this team) algorithms are required to integrate the bias RWA control and desaturation. The magnetic field model needs to be upgraded to utilize the accuracy of the magnetometer to meet the tighter knowledge requirements. Processor loading with the new capabilities needs to be evaluated.

Assess the Subsystem TRL

- Assess the Subsystem TRL (TRL 5)
  - The lowest component TRL is 5 so the subsystem TRL is no greater than 5.
  - The difficulty of integration of the upgraded magnetic torquers with the bias reaction wheel, developing the new control algorithms, incorporating the upgraded magnetic field model, and verifying the software and processor loading is understood sufficiently to not lower the TRL.
    - All of these types of components are regularly integrated in standard systems so the difficulty of integration is considered low. Only standard engineering development is required for integration.
    - Modeling of the system, including hardware models for the COTs components indicates that the system will meet requirements.
- TRL 5 Exit Criteria - "Documented test performance demonstrating agreement with analytical predictions. Documented definition of scaling requirements."
  - In this case, a strong argument can be made that the components are well-characterized and the integration of these elements is standard engineering.
  - Environments at the subsystem level are encompassed by the engineering design. (e.g., thermal design)
  - Scaling requirements are understood and estimates have been included in the modeling.
- Simulation description and results are included in the proposal to demonstrate the expected performance.
    - Assumptions of component and software capabilities are provided and have a sound basis in similarity to previous elements.

Component Path to TRL 6

- Plans are required to develop the two TRL 5 components to TRL 6
  - A high fidelity prototype of the scaled-up magnetic torquers needs to be built and tested in a relevant environment.
    - Performance parameters needed to demonstrate agreement with the simulation need to be defined (e.g., torque output, power consumption, magnetic emissions) and test plans developed to measure these parameters.
    - Relevant environment needs to be defined and compatibility demonstrated. Since magnetic torquers are susceptible to mechanical environments, vibration and shock testing are identified. Loads can probably be verified by similarity and analysis. Vacuum is not typically a driver for these components (i.e., they behave similarly in vacuum) so is probably not required.
    - Parts need to be evaluated for radiation tolerance and shown to meet requirements of 24 months in LEO.
  - The software needs to be prototyped and executed on the target processor.
    - Performance parameters needed to demonstrate agreement with the simulation (e.g., magnetic model accuracy) and meeting requirements (e.g., processor utilization) need to be defined and demonstrated.
    - The relevant environment is encompassed by the target processor and evaluation of radiation effects by analysis.

Subsystem Path to TRL 6

- A plan is required to develop the Subsystem to TRL 6
  - The interactions of the various components is critical to the performance of the subsystem and validating the simulation results. Consequently, component TRL is insufficient to establish Subsystem TRL
    - Although the integration difficulty did not lower the estimated TRL, it does not mean that integrated testing is not needed to demonstrate performance
  - Build up of a prototype cubesat with parameters relevant to ADCS testing (e.g., mass, moments-of-inertia), with prototype components appropriately mounted, and running the prototype software in the processor is needed.
  - Appropriate testing is required to demonstrate performance in a relevant environment and documented test performance demonstrating agreement with the simulation results ("analytical predictions").
    - A combination of testing may be required since all relevant environments may not be achievable simultaneously
      - For example: immersion into a Helmholtz cage simulation of a realistic on-orbit (time-varying geomagnetic field) to verify the magnetometer/magnetic torquer interactions. Simulations with an air bearing table may be used to verify the control interactions. These results are then combined analytically.
      - The need for these tests to be conducted in vacuum is assessed and included in the test plan, if required.
- TRL 6 is achieved with documented test results demonstrating agreement with the simulations and that all critical performance requirements are met. In addition, all components have achieved TRL 6 for their relevant environments and critical operating conditions.