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The launch vehicle is designed and developed during this phase. Various production and operation phase capabilities are also defined and put in place. Manufacturing plans are developed with a focus on manufacturing risk reduction. The design incorporates producibility through manufacturing requirements. Design of operational flight information, temporary monitoring measurements, engineering flight information (post flight analysis and catastrophic flight reconstruction data), vehicle diagnostics, and flight prognostic data are conducted. Verification and validation approaches include operations and logistics and supportability capabilities. Flight test plans incorporate logistics and supportability demonstration objectives. Operations control teams and centers, and operational communications are developed.

Failure Modes and Effects Analysis (FMEA), Fault Trees, Probabilistic Risk Assessments (PRA), reliability allocations are all conducted during this phase. These critical assessments provide key information for maintenance planning, crew abort conditions, and contingency time lines.

The ILSP establishes the complete logistics footprint and approach, personnel and certification requirements, and data capture and access. Key logistics and support characteristics addressed by the design include launch availability, launch and mission reliability, maintainability (maintenance down time). These characteristics drive the processing and launch countdown time lines. Design assessments are conducted in conjunction with each major design review considering ability to accommodate technology refresh, obsolescence upgrades, SCM replacements over the program life cycle. Maintenance concepts are defined including on pad maintenance, roll back maintenance, and depot maintenance. Logistics and support data are provided to support various program reviews including major design reviews, Key Decision Points (KDP), cost audits, etc. A Maintenance Task Analysis (MTA) and Level of Report Analysis (LORA) are conducted to determine detailed maintenance procedures, LRUs, and sparing needs.

The DoD model addressed both Reliability Centered Maintenance and Condition Based Maintenance. The applicability of these concepts depends on the vehicle concept. Expendable launch vehicle maintenance is reactive to failure conditions. While some preventative maintenance is defined, most maintenance actions are corrective based on the occurrence of a failure condition. Since the life cycle of the vehicle is predominantly during the assembly phase, the failures are not expected due to operational cycles or use. Thus, neither RCM nor CBM apply well. For re-useable launch vehicles, however, RCM and CBM apply as described in the DoD model. These concepts can be applied after each flight and after a set number of flights through the life of the vehicle (which may encompass the life of the program).

TOC estimates are refined from the ROM level to specific Production and Operations cost requirements to be met by manufacturing, transportation, assembly, test, launch, flight operations, and post flight analysis. Affordability throughout the vehicle life cycle must purposefully and explicitly managed during the design and development phase.

### **C. NASA Production & Operations (Phase E)**

Production and Operations Activities (Phase E) for a launch vehicle involves the manufacture, assembly, integration, test, and launch operation for the operational missions supported. For a launch vehicle this period is generally decades in length which must be considered in the supportability assessments conducted early in the vehicle definition and design phases (Phases A, B, C).

The key concepts for launch vehicle application right sizing of the production base. These concepts are categorized as Low Rate Initial Production (LRIP) and Full Rate Production (FRP). For a launch vehicle, production of early blocks, which may involve a subset of customer uses and missions, can be considered LRIP. Basic production capabilities are exercised, but full production capacity is not in place. Expansion to include the full rate production must be in place while the tooling and potential facility costs are deferred until the launch vehicle customers are available/ready to support higher production rates. Early demonstration missions may be more economically supported with LRIP.

FRP is achieved when the full set of missions and customer needs can be accommodated by the production capacity. This capacity must consider the average and peak flows. High launch rate periods may be accommodated through a variety of techniques including temporary storage of stages or vehicles, multiple vehicle processing lines at the launch site, and multiple shift work. The FRP capacity must also consider low flow rates. If the peak rate is used for sizing the production base, then long periods of over production could unintentionally be realized driving up costs to the launch vehicle providers and customers. Average production rates with some surge capacity are generally better than peak rate sizing.

These concepts affect logistics planning drastically. The logistics and support capabilities must be expandable to cope with the increase from LRIP to FRP. Logistics and support must also be able to affordably support surge capacities once FRP is realized.

In addition to production, operations must be planned efficiently. Launch and flight operations are generally more efficiently handled as a consolidated team rather than separate teams. The skills to support launch operations are the same as flight operations with the exception of the launch site systems.

A key aspect to managing P&O phase costs is to conduct regular program Operational Assessments. These assessment cycles should be set based on funding cycles from stakeholders and customers. Major planned block upgrades should be associated with a program assessment of logistics, supportability, and operations efficiency at the initial of block developments and as the block upgrade is brought into operational use.

#### **D. NASA Decommissioning (Phase F)**

Program Close out (Phase F) involves the orderly shutdown of the program including disposition of remaining assets, transition of manufacturing facilities, and the capture and retention of lessons learned and key technical data for historical purposes and potential application on future launch vehicle developments. These plans must be put in place with sufficient time to affect and orderly shutdown of the program. This is a long lead activity that needs to be planned at least 5 years before the decommissioning date in order to properly disposition and transfer assets.

### **V. Conclusion**

System Operational Effectiveness provides a strong methodology and framework from which to measure and manage the effectiveness of a launch vehicle performance, availability, and process efficiency. The framework maps well to the NASA launch vehicle development and operations concepts. SOE methodology provides an assessment approach in which technical performance metrics can be defined, integrated, and related to provide a more complete understanding of the vehicle capabilities and support systems. In order to achieve affordable operational effectiveness, the launch vehicle must be designed for support and the support systems must support the design. This relationship is essential as no processes can compensate for a vehicle not designed for support. As the launch vehicle moves from definition through design, the SOE measures and focus change with the design maturity. The focus shifts from design for support as these capabilities are designed in to the vehicle to support definition for the design. This yields a launch vehicle with matching support capabilities ready for mission support beginning with the first launch. As the program moves to the P&O phase, the production base must be right sized to the anticipated mission flow rate. The concepts of LRIP and FRP provide a basis from which to transition from low early mission launch rates to higher mission rates as the program matures and the customer base expands. The production base in this case must be able to accommodate surge capacities to keep from over sizing the production base. Logistics and support capabilities must be scalable with the production capacities as the program moves from LRIP to FRP.

### **References**

<sup>1</sup> Beck, Jerry; Verma, Dinesh; Parry, Tom; “Designing and Assessing Supportability in DoD Weapons Systems: A Guide to Increased Reliability with Reduced Logistics Footprint”, Oct 2003.

<sup>2</sup> Beck, Jerry; Verma, Dinesh; Parry, Tom; “Designing and Assessing Supportability in DoD Weapons Systems: A Guide to Increased Reliability with Reduced Logistics Footprint”, Oct 2003, pg. 10.

<sup>3</sup> Beck, Jerry; Verma, Dinesh; Parry, Tom; “Designing and Assessing Supportability in DoD Weapons Systems: A Guide to Increased Reliability with Reduced Logistics Footprint”, Oct 2003, pg. 19.

<sup>4</sup> Griffin, Michael, “How Do We Fix System Engineering?”, 61st Annual International Congress, Prague, Czech Republic, 27 Sept – 1 Oct 2010.

<sup>5</sup> Beck, Jerry; Verma, Dinesh; Parry, Tom; “Designing and Assessing Supportability in DoD Weapons Systems: A Guide to Increased Reliability with Reduced Logistics Footprint”, Oct 2003, pg. 9.

<sup>6</sup> Beck, Jerry; Verma, Dinesh; Parry, Tom; “Designing and Assessing Supportability in DoD Weapons Systems: A Guide to Increased Reliability with Reduced Logistics Footprint”, Oct 2003, pg. 11.

<sup>7</sup> NASA Systems Engineering Processes and Requirements, NPR 7123.1A.

