























effective launch vehicle. Technology starts in Pre-Phase A and continues into Phase A. In general, critical technologies for development of the launch vehicle, in particular high risk technologies, need to be completed before the System Readiness Review (SRR) where the launch vehicle requirements are approved for start of design activities. This phase also includes the preliminary design of the launch vehicle culminating in the PDR. All technologies must be ready to support implementation by PDR. During this pre-systems acquisition phase, the mission context and launch vehicle concepts must be well understood including the operations and supportability requirements. These requirements are essential to cost effective operations during the Operations Phase.

During this phase, 80% of the vehicle production and operations costs are established in terms of the operations and support capabilities supported by the vehicle design. The launch vehicle concept is captured in the Concept of Operations Document and defines the missions and customers to be supported, flight rates, launch site location and environment, system effectiveness, launch vehicle life cycle, and launch vehicle program life cycle. For an expendable vehicle, the launch vehicle life cycle is the time from start of manufacture through mission completion. The program life cycle is from the start of concept definition through program decommissioning (Phase F). In conjunction with the vehicle concept, the launch vehicle support and maintenance concepts are defined which includes launch reliability, expected maintenance rates (which determine processing and launch time lines and maintenance access needs), and obsolescence expectations over the program life cycle.

Technology development is a key aspect of Pre-Phase A and Phase A. This phase involves the maturation of new capabilities necessary to achieve the launch vehicle concepts for capabilities, production and operations, and affordability. Technology demonstrations include demonstration of key supportability concepts. This is particularly important in early launch vehicle test flights. Demonstrations may also be conducted on related vehicle such earlier variants in the launch vehicle family. Key tests during early development activities should be included as part of the System Development Plan (SDP).

The launch vehicle logistics and support concepts are captured in the Integrated Logistics Support Plan (ILSP). This defines the key driving philosophies to accomplish the affordability and sustainment goals during the Production and Operations phase (Phase E). The ILSP addresses the logistics footprint (on-site maintenance, depot maintenance, sparing policy); line replaceable unit (LRU) definition; personnel skills, training, and certification; supply chain management (SCM); and supportability risks. Production and Operation metrics should be captured in the programs technical metrics. In addition, a Failure Management Plan addresses response to processing, launch, and flight failures. A Rough Order of Magnitude (ROM) TOC is completed to define major cost drivers in vehicle capabilities and support plans.

The program risks at this point should consider not only development risks but also the production and operation risks against the launch vehicle operational uses and missions. The output of this phase results in the System Requirements Review (SRR) where the launch vehicle requirements or specifications are base lined.

## B. NASA Systems Acquisition (Phases C & D)

Systems Acquisition encompasses Final Design and Fabrication (Phase C) along with Vehicle Assembly, Integration & Test, and Launch Operations (Phase D). This phase includes the final design activities of the launch vehicle, verification and validation of the design. In addition, assembly, integration, test and launch operations of

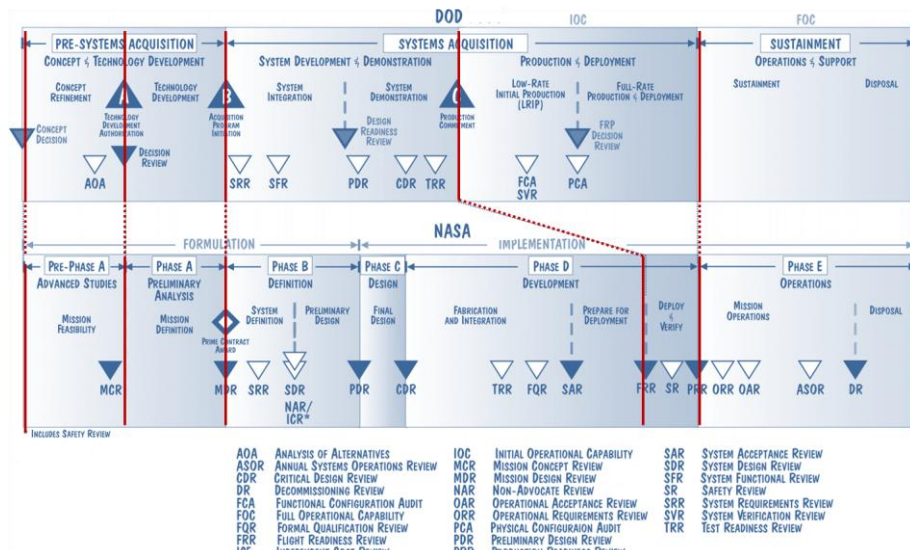


Figure 8. Mapping of DoD Life Cycle Phases to NASA Project Life Cycle Phases

the first flight vehicle are conducted in this phase. Depending on the program, more than one test flight may be involved in this phase.

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.

