# Ship Reliability Growth – New Ship Example

The following example is for the USS *Reliable* (ABC 10) ship class. The ABC 10 class is the replacement class for the USS *Unreliable* (ABC 1) class ship.

**ABC 10 Reliability Growth Strategy Overview**

The ABC 10 reliability growth strategy was developed in accordance with MIL-HDBK-189C, DoD Handbook on Reliability Growth Management. The ABC 10 Reliability Growth Strategy was developed to capitalize on the lessons learned from the legacy ABC 1 program. Failure modes identified in ABC 1 have been identified and their fixes applied to the ABC 10. Additionally, the majority of the equipment that will be used to construct the ship has several years of demonstrated reliability.

The reliability growth strategy leverages critical equipment, integrated sub-systems, and ship-level testing to assess Reliability, Availability and Maintainability (RAM). These critical pieces of equipment are expected to be the primary reliability drivers for ABC 10 and include: main engines, propulsion subsystems, C4N hardware and software, auxiliary and electrical power generation subsystems. The reliability growth strategy will focus on these critical systems. Equipment level testing serves to identify and correct design weaknesses early in the program. Reliability block diagrams and simulation tools (Raptor Reliability Simulation Software) and were used to determine reliability requirements for selected critical equipment (main engines, APUs, etc). Equipment level reliability growth curves have been developed and will be utilized to monitor reliability growth during equipment level testing. It is expected that critical equipment will be responsible for 58% of the failures (reference the ABC 10 RAM Predictions and Analysis Report).

The Shipbuilders a robust RAM program is described in more detail in the reliability program plan. Key elements include:

- Development and analysis of component/system level RAM modeling
- Implementation of RAM predictions/allocation, to include quantitative RAM requirements in Shipbuilder/vendor procurement specifications
- Conduct a Failure Mode, Effects and Criticality Analysis (FMECA)
- Develop and apply operational and environmental life cycle loads when selecting equipment/components
- Perform maintainability demonstrations
- Implement a Failure Reporting, Analysis and Corrective Action System (FRACAS)
- Use a Government led Failure Reporting Board (FRB)
- Conduct equipment and ship-level reliability growth testing.

**critical equipment**

In order to adequately assess the reliability of the critical equipment, adequate testing was allocated for five ABC 10 critical systems. Table 1 shows the dedicated hours of reliability testing for each of the critical systems. Sufficient test time at the equipment level has been allocated to discover and fix equipment level failures.

**Table 1. Hours of Reliability testing for each ship subsystem from predesign to IOT&E.**

| System | Cumulative System Hours Prior to Shipboard Installation | | Quantity per ship | Cumulative Ship-Level Testing | |
|---|---|---|---|---|---|
| | Operating Hours from Prior Testing not under the ABC 10 program | System Testing at shipyard prior to ship installation | | Contractor Test Hours | Government Test Hours |
| **Main Engines** | 10,200 | 1,416 | 4 | 960 | 960 |
| **Propulsion System** | | 104 | 2 | 480 | 480 |
| **C4N System** | | 1,210 | 1 | 240 | 240 |
| **Auxiliary System** | 500 | 1,204 | 1 | 240 | 240 |
| **Electrical Generation** | 1,000 | 304 | 2 | 480 | 480 |

In order to develop a ship-level reliability growth model, equipment-level testing is used to determine the initial ship-level MTBF entering the Shipbuilder test phase of ship-level testing, the management strategy required for successful Shipbuilder and Government testing, and the ability to achieve the respective equipment-level MTBFs in support of the threshold MTBF requirement.

The goal is to grow to an effective ship-level MTBF of 32.5 hours, while ABC 10 is underway. Derivation of the effective ship-level MTBF (aka, threshold MTBF) underway is described below. Although the ship-level MTBF 32.5 hours for underway time will be used to measure the ship's reliability growth, reliability data will be recorded for all phases of testing.

**MTBF While Underway Derivation**

The six phases of the Design Reference Mission profile is described in Table 1. The most stressing mission phases from a reliability perspective are mission phases B and C where the ship is actually underway. Therefore, the underway periods will be used to derive a reliability underway requirement.

**Table 2. ABC 10 Mission Phases and Reliability Predictions**

| Mission Phase | Predicted Mission Phase MTBF | Time in Phase | Predicted Reliability | Derived Required Reliability |
|---|---|---|---|---|
| **Phase A: Mission Prep** | 481 | 1.88 | 0.996 | 0.996 |
| **Phase B/C: Transit with and without payload (aka., underway)** | 41.2 | 4.12 | 0.905 | 0.88 |
| **Phase D: Loiter** | 206 | 2.85 | 0.986 | 0.986 |
| **Phase E: Off-load** | 168 | 0.95 | 0.994 | 0.994 |
| **Phase F: On-Load** | 451 | 2.20 | 0.995 | 0.995 |
| **Total Mission Time** | | 12.0 | **0.88** (Product of above reliabilities) | **0.85** (Product of above reliabilities) |

The effective ship-level MTBF is based on the threshold reliability requirement of 85% (0.85) for the 12-hour mission requirement. This overarching reliability requirement can be decomposed into reliability requirements for each phase. The predicted reliabilities in Table 1 are based on reliability block diagrams and critical system growth curves. The high predicted reliabilities (and agreement among all stakeholders that these predicted reliabilities are reasonable) for phases A, D, E, and F provide flexibility in an underway requirement. The system level requirement of 85% can be achieved with an underway (Phase B/C) reliability of 88%. Using the exponential distribution we can solve for a required underway MTBF of 32.5 hours:

$$\text{MTBF (underway)} = \frac{-4.12 \text{ hours}}{\ln(0.88)} = 32.5 \text{ hours}$$

**Reliability Growth Planning Software Tool**

ReliaSoft's RGA 7® software modeling tools were selected to develop the ABC 10 reliability growth plan. RGA 7® software modeling tools have been validated for use on DoD programs. The RGA 7® modeling tools employ the Crow Extended model for reliability growth projections and the Crow Extended - Continuous Evaluation model that provides for iterative reliability growth plan adjustments once test data becomes available. For reliability growth planning, the ABC 10 program applied the Crow Extended reliability growth projection module.

**Reliability Growth Strategy Methodology and Assumptions**

As described in Section 1.0, the ABC 10 ship reliability growth strategy involves equipment-level and ship-level assessment processes designed to capitalize on lessons learned from the legacy ABC 1 program; equipment/systems that possess demonstrated reliability performance; and equipment, integrated and ship-level reliability growth testing to achieve the ship-level MTBF requirement. The following sections provide details for the inputs and assumptions that were applied, the systems that were assessed and the accounting of their respective test hours, and the methodology and results for reliability growth at the equipment-level and ship-level.

### Inputs and Assumptions

The Crow Extended model was used to construct the equipment-level and ship-level reliability growth curves previously described at an 80% confidence level. The supporting input values, assumptions and rationale are described below.

- Input Parameter:
  - Management Strategy = 0.75.
  - Assumption: The Shipbuilder and Government will implement fixes for 75% of the failure modes that have been identified in order to reduce the likelihood that the revised product design will fail due to those particular failure modes.
  - Rationale: Extensive equipment-level testing and prior demonstrated reliability of most systems resulted in a management strategy calculated at ship-level to be 0.75.

- Input Parameter:
  - Average Fix Effectiveness = 0.70.
  - Assumption: On average, corrective measures or fixes are effective 70% of the time. At this stage of the plan, the parameter represents an average value for all failure modes subject to corrective action.
  - Rational: Crow extended modeling recommends an initial overall value of 0.70.

### Equipment-Level Reliability Growth

Reliability growth curves were constructed for each of the critical systems. The focus was to grow reliability on each of the sub-systems to a point where the full system level requirement can be achieved. The predicted values from column 4 of Table 2 were used as the growth goals for the equipment level growth curves. The individual reliability growth curves for the equipment level curves are in the reliability program plan.

### Ship-Level Reliability Growth

The ship-level reliability growth model was developed based on the equipment-level reliability assessment. The strategy assumes 240 hours of ship-level test time required by the Shipbuilder in accordance with the contract and 240 hours of estimated reliability growth test hours to be performed by the Government, and the input parameters described above as the inputs for the growth model

The initial MTBF was determined to be 20.9 hours based on the equipment-level assessment with a calculated management strategy of 0.75, which conservatively accounts for corrective actions/fixes expected to be in place after equipment-level testing and at entry into the Shipbuilder Ship-level test phase. The effective ship-level MTBF of 32.5 hours is reached within the 480 hour test period at a Growth Potential Design Margin (GPDM) of 1.35. Note that the GPDM value reflects the system's design maturity and required quality/reliability level as well as the program's level of aggressiveness. Figure 1 illustrates the reliability growth curve at the ship-level.