

## Chapter 6

### SYSTEMS ENGINEERING ACTIVITIES AND PRODUCTS

#### SUMMARY

This Chapter provides a detailed listing of project activities and products which form the systems engineering process as applied to each project life cycle phase.

#### 6.1 INTRODUCTION

This Chapter includes a detailed list of activities and products. Emphasis is placed on the cyclical nature of the systems engineering process leading to progressive and more detailed refinement of the system requirements.

#### 6.2 FORMULATION PHASE: PRE-PHASE A - PRELIMINARY REQUIREMENTS AND CONCEPTS ANALYSIS

#### PRE-PHASE A - PROJECT ACTIVITIES AND PRODUCTS

(Systems Engineering activities are shown in bold italics.)

#### 1. PROJECT INITIALIZATION

| Activities   | Products   |
|--|--|
| 1. Request for Pre-Phase A study by sponsoring management    | 1. Request for support of required organizations |
| 2. Establish Pre-Phase A Team                                | 2. Assigned study team                           |
| 3. Initial briefing to study team by sponsoring organization | 3. Informal presentation                         |
| 4. Develop project strategy                                  | 4. Pre-Phase A Work Plan                         |
| 5. <i>Establish Project Data Base</i>                        | 5. <i>Project Data Base</i>                      |

**PRE-PHASE A - PROJECT ACTIVITIES AND PRODUCTS**

(Systems Engineering activities are shown in bold italics.)

**2. USER NEEDS AND GOALS ANALYSIS**

| Activities   | Products  |
|--|---|
| 6. Formal presentation to study team by sponsoring group<br>6.1 Document known project constraints and control items   | 6. Presentation materials   |
| 7. <i>Document science and technology goals</i>  | 7. <i>Statement of Project Status</i><br>7.1 <i>Project goals</i><br>7.2 <i>Experiment maturity</i><br>7.3 <i>Known constraints</i>         |
| 8. <i>Perform goals analysis</i><br>8.1 <i>Establish the relationship between science and technology goals and NASA/LaRC goals</i><br>8.2 <i>Establish impact and vision of the experiment</i> | 8. <i>Preliminary Goals Analysis Document</i><br>8.1 <i>Project Justification Statement</i><br>8.2 <i>Project Impact / Vision Statement</i> |
| 9. <i>Establish goals hierarchy</i>  | 9. <i>Goals Hierarchy</i>   |

3. SYSTEMS REQUIREMENTS AND CONSTRAINTS

| Activities  | Products   |
|---|--|
| <p><i>10. Document project requirements and constraints (concept independent)</i></p> <ul style="list-style-type: none"> <li><i>10.1 Document science and technology requirements</i></li> <li><i>10.2 Develop instrument requirements</i></li> <li><i>10.3 Develop spacecraft requirements</i></li> <li><i>10.4 Develop mission, flight operations, and ground support operations requirements</i></li> <li><i>10.5 Develop preliminary hardware/software requirements</i></li> <li><i>10.6 Document management requirements</i></li> <li><i>10.7 Develop preliminary requirements verification and validation plan</i></li> </ul> | <p><i>10. Preliminary Systems Requirements Document</i></p> <ul style="list-style-type: none"> <li><i>10.1 Science and technical requirements</i></li> <li><i>10.2 Instrument requirements</i></li> <li><i>10.3 Spacecraft requirements</i></li> <li><i>10.4 Mission, flight operations, and ground operations requirements</i></li> <li><i>10.5 Hardware/software requirements</i></li> <li><i>10.6 Project requirements</i></li> <li><i>10.7 Requirement originator</i></li> <li><i>10.8 Requirement responsibility</i></li> <li><i>10.9 Initial requirements verification and validation plan; preliminary test plan</i></li> </ul> |
| <p><i>11. Establish requirements database</i></p>   | <p><i>11. Requirements Data Base</i></p>   |

PRE-PHASE A - PROJECT ACTIVITIES AND PRODUCTS  
(Systems Engineering activities are shown in bold italics.)

4. PERFORMANCE MEASURES

| Activities  | Products   |
|---|--|
| <p><i>12. Document initial performance criteria measures from goals hierarchy</i></p> <ul style="list-style-type: none"> <li><i>12.1 Identify the performance criteria measures</i></li> <li><i>12.2 Determine the relative importance of the performance measures</i></li> </ul> | <p><i>12. Initial Performance Measures Statement</i></p> <ul style="list-style-type: none"> <li><i>12.1 Performance measures list</i></li> <li><i>12.2 Performance measures relative importance</i></li> </ul> |

5. SYSTEMS CONCEPTS

| Activities   | Products   |
|--|--|
| 13. Develop preliminary alternate system concepts<br>13.1 Instruments<br>13.2 Spacecraft<br>13.3 Launch vehicle<br>13.4 Mission<br>13.5 Ground operations<br>13.6 Flight operations<br>13.7 Interfaces | 13. Broad-based list of potential system concepts to satisfy experiment requirements |
| 14. <i>Evaluate and document alternate system concepts</i>   | 14. <i>Preliminary Alternate Concepts List</i>                                       |

6. CONCEPTS ANALYSIS

| Activities   | Products  |
|--|---|
| 15. <i>Characterize alternate system concepts</i><br>15.1 WBS<br>15.2 Schedule<br>15.3 Cost<br>15.4 Risk<br>15.5 <i>Technical Performance Measures</i><br><i>(concept modeling, simulation, functional analysis, engineering analysis techniques, as required)</i> | 15. <i>Initial Alternate Concepts Analysis Document</i><br>15.1 <i>Preliminary WBS</i><br>15.1 <i>Preliminary schedule</i><br>15.1 <i>Preliminary cost estimate</i><br>15.1 <i>Preliminary risk assessment</i><br>15.1 <i>Preliminary interface definition, operations scenario, flight classification, performance measure estimates</i><br>15.1 <i>Required technology developments</i> |

## PRE-PHASE A - PROJECT ACTIVITIES AND PRODUCTS

(Systems Engineering activities are shown in bold italics.)

### 7. CONCEPTS RANKING

| Activities   | Products   |
|--|--|
| <i>16. Rank concepts based on performance measures</i><br><i>16.1 Perform trade studies</i><br><i>16.2 Perform multi-attribute decision analysis</i> | <i>16. Concept Ranking Report</i><br><i>16.1 Trade study results</i><br><i>16.2 Decision analysis results</i><br><i>16.3 Phase A Go/No Go recommendation</i> |

### 8. SYSTEMS DEVELOPMENT

| Activities  | Products  |
|---|---|
| <i>17. Prepare Phase A Study Plan</i>                     | <i>17. Proposed Phase A Study Plan</i><br><i>17.1 Systems engineering management plan</i> |
| 18. Prepare for Sponsoring Group Director's Review (SGDR) | 18. SGDR Review Package   |

### 9. REVIEW, VERIFICATION, AND VALIDATION

| Activities                             | Products                            |
|--|-------------------------------------|
| 19. Sponsoring Group Director's Review | 19. SGDR summary and recommendation |

### 10. DECISION POINT

| Activities                   | Products                 |
|------------------------------|--------------------------|
| 20. Phase A Project Approval | 20. Go/No Go for Phase A |

6.3 FORMULATION PHASE:  
 PHASE A - REQUIREMENTS DEFINITION AND CONCEPTUAL TRADE STUDIES

PHASE A - PROJECT ACTIVITIES AND PRODUCTS  
 (Systems Engineering activities are shown in bold italics.)

1. PROJECT INITIALIZATION

| Activities   | Products   |
|--|--|
| 1. Appoint Project Manager for Phase A Study   | 1. LaRC Announcement                                   |
| 2. Establish Phase A Team  | 2. Memorandum of Understanding between Division Chiefs |
| 3. Review Phase A Study Plan   | 3. Final Phase A Study Plan                            |
| 4. Review Pre-Phase A product  | 4. Phase A Team Building                               |
| 5. Assign team responsibilities  | 5. Project Manager Memorandum                          |
| 6. Develop business, management and technical plans<br>6.1 Prepare initial System Acquisition Plan | 6. Phase A Work Plan and System Acquisition Plan       |

2. USER NEEDS AND GOALS ANALYSIS

| Activities                                     | Products                                       |
|--|--|
| <i>7. Review and update the goals analysis</i> | <i>7. Review and update the goals analysis</i> |

3. SYSTEMS REQUIREMENTS AND CONSTRAINTS

| Activities  | Products   |
|---|--|
| <p><i>8. Complete the project requirements and constraints</i><br/> <i>8.1 Develop the System Requirements Document</i><br/> <i>8.2 Refine/define requirements verification and validation plan</i></p> | <p><i>8. Project requirements documentation</i><br/> <i>8.1 Systems Requirements Document with Science, Instrument, Mission, Spacecraft, Hardware / Software, Operations and Project requirements</i><br/> <i>8.2 Preliminary Verification and Validation Plan</i></p> |

PHASE A - PROJECT ACTIVITIES AND PRODUCTS  
 (Systems Engineering activities are shown in bold italics.)

4. PERFORMANCE MEASURES

| Activities   | Products  |
|--|---|
| <p><i>9. Refine performance measures</i><br/> <i>9.1 Refine relative importance</i><br/> <i>9.2 Develop decision analysis for each performance measure</i></p> | <p><i>9. Performance Measures Statement</i></p> |

5. SYSTEMS CONCEPTS

| Activities   | Products                                  |
|--|---|
| <p><i>10. Review and refine alternate systems concepts</i></p> | <p><i>10. Alternate Concepts List</i></p> |

6. CONCEPTS ANALYSIS

| Activities   | Products  |
|--|---|
| <p>11. <i>Perform a refined trade-off analysis on the alternate concepts</i></p> <ul style="list-style-type: none"> <li>11.1 <i>WBS</i></li> <li>11.2 <i>Schedule</i></li> <li>11.3 <i>Cost</i></li> <li>11.4 <i>Risk</i></li> <li>11.5 <i>Cost/Risk Analysis</i></li> <li>11.6 <i>Concept technical simulation</i></li> </ul> <p>- (each technical performance measure will be evaluated through simulation models; the completeness of the model should reflect the parameters ranking)</p> <ul style="list-style-type: none"> <li>11.7 <i>Develop probability distribution for each performance measure for each alternative concept as applicable</i></li> </ul> | <p>11. <i>Alternate Concepts Analysis Document (All concepts)</i></p> <ul style="list-style-type: none"> <li>11.1 <i>WBS</i></li> <li>11.2 <i>Schedule</i></li> <li>11.3 <i>Preliminary life cycle cost estimate</i></li> <li>11.4 <i>Risk assessments</i></li> <li>11.5 <i>Interface definitions</i></li> <li>11.6 <i>Required technology development</i></li> <li>11.7 <i>Results of simulation analysis for each technical performance measure</i></li> <li>11.8 <i>Probability distribution for projected concept values on each performance measure</i></li> </ul> |

7. CONCEPTS RANKING

| Activities   | Products  |
|--|---|
| <p>12. <i>Perform multi-attribute decision analysis</i></p> <ul style="list-style-type: none"> <li>12.1 <i>Perform decision analysis</i></li> <li>12.2 <i>Perform sensitivity analysis</i></li> <li>12.3 <i>Decide feasibility of project</i></li> </ul> | <p>12. <i>Decision Analysis Report</i></p> <ul style="list-style-type: none"> <li>12.1 <i>Decision analysis results</i></li> <li>12.2 <i>Sensitivity analysis results</i></li> <li>12.3 <i>Phase B Go/No Go recommendation</i></li> </ul> |

**PHASE A - PROJECT ACTIVITIES AND PRODUCTS**  
 (Systems Engineering activities are shown in bold italics.)

**8. SYSTEMS DEVELOPMENT**

| Activities   | Products   |
|--|--|
| <b><i>13. New Start Proposal</i></b><br><b><i>13.1 Prepare proposed Project Plan</i></b><br><b><i>13.2 Perform risk assessment</i></b> | <b><i>13. Preliminary New Start Proposal</i></b><br><b><i>13.1 Draft Project Plan with statement of project goals, justification, and impact</i></b><br><b><i>13.2 Statement of ranked concepts</i></b><br><b><i>13.3 Results of decision analysis</i></b><br><b><i>13.4 Preliminary Risk Reduction Plan</i></b><br><b><i>13.5 Preliminary Configuration Control Plan</i></b><br><b><i>13.6 Mission Needs Statement (if req'd)</i></b> |
| <b>14. Prepare Project Initiation Agreement (PIA)</b>  | <b>14. Proposed PIA</b>  |
| <b>15. Prepare Phase B Study Plan</b>  | <b>15. Proposed Phase B Study Plan</b><br><b>15.1 Technical and Management Plan</b><br><b>15.2 Systems Engineering Management Plan</b>   |
| <b>16. Prepare for reviews</b>   | <b>16. Phase A Review Packages</b><br><b>16.1 PSRR Review Package</b><br><b>16.2 SEIRC Review Package</b><br><b>16.3 Group Directors' Review Package</b>   |

**9. REVIEW, VERIFICATION, AND VALIDATION**

| Activities   | Products  |
|--|---|
| <b>17. Preliminary Systems Requirements Review</b>                             | <b>17. PSRR Committee summary and concurrence</b> |
| <b>18. Space-flight Experiment Initiatives Review Committee (SEIRC) Review</b> | <b>18. SEIRC summary and concurrence</b>          |
| <b>19. Group Directors' Review</b>   | <b>19. Management approval</b>                    |

|  |   |
|--|---|
| 20. LaRC Center Director's Review                | 20. Management approval to present to NASA Headquarters |
| 21. NASA Headquarters Review of proposed project | 21. NASA Headquarters approval to proceed to Phase B    |

**PHASE A - PROJECT ACTIVITIES AND PRODUCTS**  
 (Systems Engineering activities are shown in bold italics.)

10. **DECISION POINT**

| Activities                   | Products  |
|------------------------------|---|
| 22. Phase B Project Approval | 22. Project Initiation Agreement (PIA) approved |

6.4 **FORMULATION PHASE:**  
**PHASE B(1) - CONCEPT DEFINITION AND PRELIMINARY DESIGN**

**PHASE B(1) - PROJECT ACTIVITIES AND PRODUCTS**  
 (Systems Engineering activities are shown in bold italics.)

1. **PROJECT INITIALIZATION**

| Activities   | Products   |
|--|--|
| 1. Obtain authorization for Project Phase B based on proposed Project Plan and PIA   | 1. Funding authorization from NASA Headquarters to LaRC  |
| 2. Appoint Phase B Project Manager   | 2. LaRC Announcement   |
| 3. Appoint Phase B Definition Team<br>3.1 Obtain commitments from Division Chiefs  | 3. Memorandum of Understanding between Division Chiefs   |
| 4. Update and finalize the proposed Phase B Study Plan<br>4.1 Technical and management<br>4.2 <i>Systems Engineering Management Plan</i> | 4. Phase B Study Plan<br>4.1 Technical and Management Plan<br>4.2 <i>Systems Engineering Management Plan</i> |

2. USER NEEDS AND GOALS ANALYSIS

| Activities                                   | Products                                |
|--|---|
| 5. <i>Review and finalize goals analysis</i> | 5. <i>Final Goals Analysis Document</i> |

**PHASE B(1) - PROJECT ACTIVITIES AND PRODUCTS**  
 (Systems Engineering activities are shown in bold italics.)

3. SYSTEMS REQUIREMENTS AND CONSTRAINTS

| Activities  | Products                                      |
|---|---|
| 6. <i>Review and update Systems Requirements Document</i><br>6.1 <i>Place change control on Systems Requirements</i>  | 6. <i>Final Systems Requirements Document</i> |
| 7. <i>Review Project Justification, Vision, and Impact</i>  | 7. <i>Final Goals Analysis Document</i>       |
| 8. <i>Review systems requirements and constraints (Instrument, Spacecraft, Mission)</i><br>8.1 <i>Mission, orbit, launch, operations, recovery scenarios defined</i><br>8.2 <i>Electrical</i><br>8.3 <i>Thermal control</i><br>8.4 <i>Structural</i><br>8.5 <i>Attitude control</i><br>8.6 <i>Power system</i><br>8.7 <i>Command and data handling</i><br>8.8 <i>Communications</i><br>8.9 <i>Hardware and Software</i> | 8. <i>Final Systems Requirements Document</i> |

4. PERFORMANCE MEASURES

| Activities   | Products                                       |
|--|--|
| 9. <i>Review and update performance measures and relative importance</i> | 9. <i>Final Performance Measures Statement</i> |

5. SYSTEMS CONCEPTS

| Activities                                      | Products                                 |
|---|--|
| <i>10. Review and update alternate concepts</i> | <i>10. Final Alternate Concepts List</i> |

PHASE B(1) - PROJECT ACTIVITIES AND PRODUCTS  
 (Systems Engineering activities are shown in bold italics.)

6. CONCEPTS ANALYSIS

| Activities   | Products  |
|--|---|
| <i>11. Review and update Alternate Concepts Analysis Report</i><br><i>11.1 Risk assessment survey and technology development</i> | <i>11. Final Alternate Concepts Analysis Report</i> |

7. CONCEPTS RANKING

| Activities                                 | Products                                     |
|--|--|
| <i>12. Update decision analysis</i>        | <i>12. Final Decision Analysis Report</i>    |
| <i>13. Select baseline systems concept</i> | <i>13. Baseline Systems Concept Selected</i> |

8. SYSTEMS DEVELOPMENT

| Activities   | Products   |
|--|--|
| <i>14. Expand and refine baseline design; perform subsystem tradeoff analyses</i><br><i>14.1 Identify major segments, elements, sub-systems</i><br><i>14.2 Allocate requirements to segments, elements, and subsystems</i><br><i>14.3 Refine system design</i><br><i>14.4 Initiate risk reduction activities</i> | <i>14. Baseline Systems Concept Package</i><br><i>14.1 Preliminary systems decomposition and definition</i><br><i>14.2 Requirements allocation</i><br><i>14.3 Final Systems Requirements Document</i><br><i>14.4 Risk Reduction Plan, Failure Modes and Effects Analysis (FMEA), and Critical Items List (CIL)</i> |

|   |   |
|---|---|
| <p>14.5 <i>Expand WBS to subsystem level</i></p> <p>14.6 <i>Expand life cycle cost analysis</i></p> <p>14.7 <i>Expand schedule</i></p> <p>14.8 <i>Expand interface definition</i></p> <p>14.9 <i>Expand verification and validation plan</i></p> <p>14.10 <i>Prepare preliminary Interface Control Document</i></p> <p>14.11 <i>Allocate requirements to mission operations, instrument, and control software</i></p> <p>14.12 <i>Initiate Product Assurance Plan</i></p> <p>14.13 <i>Prepare final Configuration Control Plan</i></p> <p>14.14 <i>Prepare Preliminary Parts List</i></p> | <p>14.5 <i>Refined WBS</i></p> <p>14.6 <i>Updated life cycle cost estimate</i></p> <p>14.7 <i>Updated schedule</i></p> <p>14.8 <i>Final Systems Requirements Document</i></p> <p>14.9 <i>Updated Verification and Validation Plan</i></p> <p>14.10 <i>Preliminary Interface Control Document (ICD)</i></p> <p>14.11 <i>Software Requirements Spec.</i></p> <p>14.12 <i>Prelim. Product Assurance Plan</i></p> <p>14.13 <i>Initial Configuration Ctrl. Plan</i></p> <p>14.14 <i>Preliminary Parts List</i></p> |
| 15. Produce preliminary design drawings   | 15. Preliminary Design Drawings   |

**PHASE B(1) - PROJECT ACTIVITIES AND PRODUCTS**  
 (Systems Engineering activities are shown in bold italics.)

8. **SYSTEMS DEVELOPMENT** (Continued)

| Activities                                      | Products  |
|---|---|
| 16. <i>Develop systems integration document</i> | <p>16. <i>Systems Integration Document</i></p> <p>16.1 <i>Systems Integration Plan</i></p> <p>16.2 <i>Spacecraft Integration Plan</i></p> <p>16.3 <i>Launch Vehicle Integration Plan</i></p> <p>16.4 <i>Spacecraft Site Test Plan</i></p> |
| 17. Prepare Review Packages                     | 17. Review Packages for Systems Requirements Review (SRR), Non-Advocate Review (NAR), Software Concept Review (SCR), Software Requirements Review (SRR), Preliminary Design Review (PDR), Software Preliminary Design Review              |
| 18. Expand/update proposed Project Plan         | 18. Proposed Project Plan   |

9. REVIEW, VERIFICATION, AND VALIDATION

| Activities   | Products  |
|--|---|
| 19. Systems Requirements Review (SRR) and Software Concept Review (SCR)  | 19. SRR and SCR Committee summary and recommendations reports |
| 20. LaRC Review of NAR Package for Non-Advocate Review Committee   | 20. Management approval                                       |
| 21. NAR Review for Non-Advocate Committee at NASA Headquarters   | 21. Non-Advocate Committee summary and recommendations report |
| 22. Conduct Software Requirements Review (SRR)   | 22. SRR Committee summary and recommendations report          |
| 23. Conduct Preliminary Design Review (PDR) and Software Preliminary (Architectural) Design Review (SPDR) for a 70 percent complete design | 23. PDR & SPDR Committee summary and recommendations report   |

10. DECISION POINT

| Activities  | Products                              |
|---|---------------------------------------|
| 24. Obtain all management commitments for new start support and resources | 24. Approval for new start in Phase C |

6.5 FORMULATION PHASE: PHASE B(2) - SOURCE SELECTION PROCESS

PHASE B(2) - PROJECT ACTIVITIES AND PRODUCTS

(Systems Engineering activities are shown in bold italics.)

| Activities  | Products                                       |
|---|--|
| 1. Complete Systems Acquisition Plan<br>1.1 Identify items for procurement<br>1.2 Identify items for in-house build<br>1.3 Identify Government Furnished Property (GFP) | 1. System Acquisition Plan                     |
| 2. Establish procedures and identify areas to receive, calibrate, and store Contract End Items (CEI's) and GFP  | 2. Product Assurance Plan                      |
| 3. Prepare preliminary Statement of Work (SOW) or Technical Specifications for review by potential bidders  | 3. Preliminary SOW or Technical Specifications |

|   |   |
|---|---|
| 4. Prepare Procurement Package for submittal to Acquisition Division                          | 4. Approved Procurement Package   |
| 5. Confirm funds appropriated, budgeted, programmed   | 5. Approved Purchase Request  |
| 6. Develop and implement Source Selection Plan  | 6. Source Selection Plan  |
| 7. Evaluate Proposals   | 7. Source Evaluation Board (SEB) or Source Evaluation Committee (SEC) report and recommendation |
| 8. Select Contractor  | 8. Source Selection Official (SSO) selection  |
| 9. Negotiate/Award Contract   | 9. Contract Award   |
| 10. <i>Contractor Kickoff Meeting and implement "period of understanding" with Contractor</i> | 10. <i>Contractor Kickoff Meeting</i>   |

6.6 IMPLEMENTATION PHASE:  
PHASE C - FINAL DESIGN AND ENGINEERING DEVELOPMENT

PHASE C - PROJECT ACTIVITIES AND PRODUCTS  
(Systems Engineering activities shown in bold italics.)

| Activities  | Products  |
|---|---|
| 1. <i>Update and maintain the Systems Engineering Data Base</i>             | 1. <i>Systems Engineering Data Base</i>           |
| 2. Review and augment Phase C project team; appoint mission operations team | 2. Phase C Project Team; Mission Operations Team  |
| 3. Review and update Phase B products                                       | 3. Brief new project members                      |
| 4. Update the WBS   | 4. Complete WBS                                   |
| 5. Update Preliminary Parts List  | 5. Preliminary Parts List                         |
| 6. Update System Acquisition Plan--buy vs. build components                 | 6. System Acquisition Plan                        |
| 7. <i>Allocate subsystem error budgets</i>                                  | 7. <i>Error Allocation Plan</i>                   |
| 8. <i>Develop system interface specification documents</i>                  | 8. <i>Interface Control Document (ICD) update</i> |
| 9. Develop design specifications for Contract End Items (CEI's)             | 9. Design specifications for CEI's                |
| 10. Start procurement of CEI's--hardware and software                       | 10. Approved Purchase Requests                    |
| 11. Start acquiring Government Furnished Property                           | 11. Approved Purchase Requests                    |
| 12. Finalize Configuration Control Plan                                     | 12. Final Configuration Control Plan              |

|  |   |
|--|---|
| <i>13. Develop design specifications for in-house build items</i>                  | <i>13. Design specifications for in-house build items; Specifications Traceability Matrix</i> |
| <i>14. Support risk reduction activities; develop plans for engineering models</i> | <i>14. Risk Reduction Plan; Engineering Model Build and Procurement Plan</i>                  |
| <i>15. Update verification and validation plan</i>                                 | <i>15. Verification and Validation Plan; Performance Verification Matrix</i>                  |
| 16. Iterate design and analysis to produce detail system design                    | 16. Design Analysis Reports   |
| 17. Produce "Build-To" Drawings"   | 17. Build-To" drawings  |

## PHASE C - PROJECT ACTIVITIES AND PRODUCTS

(Systems Engineering activities shown in bold italics.)

| Activities  | Products   |
|---|--|
| 18. Start fabrication of engineering and prototype models (hardware and software)   | 18. Working Models   |
| 19. Finalize plans<br>19.1 Manufacturing (fabrication and assembly)<br>19.2 Testing<br>19.3 <i>Verification and validation</i><br>19.4 <i>Integration</i><br>19.5 Operations<br>19.6 Support systems<br>19.7 Facilities<br>19.8 Software production<br>19.9 Calibration<br>19.10 Science<br>19.11 Product assurance | 19. Final plans<br>19.1 Manufacturing (fabrication and assembly)<br>19.2 Testing<br>19.3 <i>Performance Verification Matrix</i><br>19.4 <i>Systems Integration Document</i><br>19.5 Mission Operations<br>19.6 Ground Support Systems<br>19.7 Facilities<br>19.8 Software Production<br>19.9 Calibration<br>19.10 Science<br>19.11 Product Assurance |
| 20. Refine and baseline<br>20.1 Life cycle cost analysis<br>20.2 WBS<br>20.3 PERT   | 20. Phase C Project Plan<br>20.1 Life Cycle Cost Analysis<br>20.2 WBS<br>20.3 PERT   |
| 21. Test engineering and prototype hardware and software models   | 21. Engineering Model Test Reports (continues through Phase D)   |
| 22. <i>Complete systems simulation model for verification of model tests and detailed analysis</i>  | 22. <i>End-to-end Systems Simulation Model</i><br>22.1 <i>Instrument Software</i><br>22.2 <i>Ground Support Software</i><br>22.3 <i>Operations Command Software</i><br>22.4 <i>Modeling and Analysis Software</i>  |
| 23. <i>Perform mission anomaly simulation</i>   | 23. <i>Operational Contingency Plan</i>  |
| 24. Schedule CDR and SCDR for hardware/ software design 95 percent  | 24. CDR Panel appointed  |

|  |   |
|--|---|
| complete   |   |
| 25. Prepare CDR package                                    | 25. CDR Package                               |
| 26. Conduct Critical Design Review (CDR)                   | 26. CDR Committee Report and Recommendations  |
| 27. Conduct Software Critical Design Review (SCDR)         | 27. SCDR Committee Report and Recommendations |
| 28. Incorporate CDR RFA's into design and write CDR report | 28. CDR Report                                |
| 29. Update "Build-To" drawings                             | 29. "Build-To" Drawings                       |

### PHASE C - PROJECT ACTIVITIES AND PRODUCTS

(Systems Engineering activities shown in bold italics.)

| Activities   | Products   |
|--|--|
| 30. Put Configuration Control into effect  | 30. Configuration Control Plan                           |
| 31. Begin fabrication of long lead, in-house build, hardware and software flight items | 31. Fabrication Control Plan                             |
| 32. Management approval to begin Phase D   | 32. Memorandum from Chairperson, CDR and SCDR Committees |

### 6.7 IMPLEMENTATION PHASE:

#### PHASE D - FABRICATION, INTEGRATION, TEST, AND EVALUATION

### PHASE D - PROJECT ACTIVITIES AND PRODUCTS

(Systems Engineering activities shown in bold italics.)

| Activities   | Products  |
|--|---|
| 1. Complete external CEI acquisition activities; update Parts List   | 1. Updated Parts List; approved Purchase Requests |
| 2. Assure readiness of facilities for assembly/test of subsystems and system (clean rooms)                   | 2. Facilities Plan                                |
| 3. Monitor and update PERT chart with emphasis on acquisition, transportation, and integration of subsystems | 3. Assembly/Integration Procedures                |
| 4. <i>Establish contingency plans for high-risk components</i>   | 4. <i>Operational Contingency Plan</i>            |
| 5. Fabricate in-house build hardware and implement software units  | 5. Update Fabrication Plan                        |

|   |   |
|---|---|
| 6. Perform subsystem verification and conduct design reviews as needed  | 6. Ad-hoc subsystem design reviews; update hardware and software design                           |
| 7. Review/refine all testing documents (parts, subsystems, and systems) | 7. Final Test Plan  |
| 8. <i>Review/refine the system integration documents</i>                | 8. <i>Update Systems Integration Document, Systems Test Procedures, Site Spacecraft Test Plan</i> |
| 9. <i>Monitor and coordinate risk reduction activities</i>              | 9. <i>Update Risk Reduction Plan</i>  |

## PHASE D - PROJECT ACTIVITIES AND PRODUCTS

(Systems Engineering activities shown in bold italics.)

| Activities   | Products   |
|--|--|
| 10. Update all operations documents (ground and flight)  | 10. Update Mission Operations Plan and Procedures                  |
| 11. Assure readiness of support equipment  | 11. Update Ground Support Equipment Operations Plan and Procedures |
| <i>12. Continuously update interface changes</i>   | <i>12. Update ICD</i>  |
| 13. Receive CET's; inspect, test, log, and locate in bonded stores; reorder as required  | 13. Product Assurance Plan; End Item Logbooks                      |
| 14. Prepare part and subsystem test procedures as required   | 14. Test Procedures  |
| 15. Conduct system and subsystem test coordination meetings (TCM) and test readiness reviews (TRR's) as required   | 15. Test Readiness Reviews   |
| 16. Assemble parts into subassemblies and assemblies and integrate software  | 16. Assembly Instructions and Drawings                             |
| 17. Test subassemblies and assemblies  | 17. Test Reports   |
| <i>18. Evaluate test results and verify systems performance per allocated requirements and error budgets</i>   | <i>18. Update Performance Verification Matrix</i>                  |
| <i>19. Feedback test results</i><br><i>19.1 Introduce design changes and redesign as required</i><br><i>19.2 Adjust interfaces as required</i><br><i>19.3 Refabricate</i><br><i>19.4 Retest</i><br><i>19.5 Update PERT</i> | <i>19. Verified Parts, Subassemblies, and Assemblies</i>           |
| 20. Assemble subassemblies and assemblies into subsystems and integrate software   | 20. Assembly Instructions and Drawings                             |
| 21. Test subsystems  | 21. Subsystem Test Report  |

|  |   |
|--|---|
| <i>22. Evaluate test results and verify systems performance per allocated requirements and error budgets</i> | <i>22. Update Performance Verification Matrix</i> |
|--|---|

**PHASE D - PROJECT ACTIVITIES AND PRODUCTS**  
(Systems Engineering activities shown in bold italics.)

| Activities   | Products   |
|--|--|
| <b>23. Feedback test results</b><br>23.1 Introduce design changes and redesign as required<br>23.2 Adjust interfaces as required<br>23.3 Re-fabricate<br>23.4 Retest<br>23.5 Update PERT | <b>23. Verified Subsystems</b>   |
| <i>24. Update and finalize systems test procedures</i>   | <i>24. Systems Test Procedures</i>   |
| <b>25. Conduct system Test Coordination Meeting (TCM), Test Readiness Review (TRR), and Software Test Readiness Review as required</b>   | <b>25. Test Readiness Reviews</b>  |
| <b>26. Assemble subsystems into the next level elements, segments, or system</b>   | <b>26. Assembly Procedures and Drawings</b>  |
| <b>27. Test system</b><br>27.1 Qualification test<br>27.2 Systems performance test<br>27.3 Ground truth verification test  | <b>27. System Test Report</b>  |
| <i>28. Evaluate test results and verify systems performance per allocated requirements and error budgets</i>   | <i>28. Update Performance Verification Matrix</i>  |
| <b>29. Feedback test results</b><br>29.1 Redesign as required<br>29.2 Adjust interfaces as required<br>29.3 Refabricate<br>29.4 Retest<br>29.5 Update PERT                               | <b>29. Verified and validated functioning system (or Functional Configuration Audit [FCA])</b> |
| <i>30. Show compliance to Verification and Validation Plan; update verification matrix</i>   | <i>30. System Verification Report</i>  |
| <b>31. Document "as-built" configuration</b>   | <b>31. As-built Documentation (or Physical Configuration Audit [PCA])</b>                      |
| <i>32. Create the systems maintenance manuals</i>  | <i>32. Systems Maintenance Document</i>  |
| <b>33. Update the mission operations manuals (SAR)</b>   | <b>33. Update Mission Operations Plan</b>  |

**PHASE D - PROJECT ACTIVITIES AND PRODUCTS**

(Systems Engineering activities shown in bold italics.)

| Activities   | Products                                    |
|--|---|
| 34. Conduct System Acceptance Review (SAR) and Software Acceptance Review  | 34. Systems Acceptance Report               |
| 35. Document all system and GSE transportation requirements and procedures | 35. Transportation and Receiving Procedures |
| 36. Ship System to integration site  | 36. Ship system                             |

**6.8 PHASE E - OPERATIONAL PHASE: PREFLIGHT AND FLIGHT MISSION OPERATIONS AND DISPOSAL**

**PHASE E - PROJECT ACTIVITIES AND PRODUCTS**

(Systems Engineering activities shown in bold italics.)

| Activities  | Products  |
|---|---|
| 1. Mission Operations Team begins training a Project Operations Control Center (POCC) and Data Processing Center (DPC)                          | 1. Mission Operations Team Training                               |
| 2. Deliver all applicable plans and procedures to the Operations Project Manager  | 2. Final Mission Operations Plan and Procedures                   |
| 3. Train Project Operations Control Center (POCC), Mission Control Room (MCR), and Data Processing Center (DPC) personnel for operations duties | 3. Final Mission Timelines and Operational Scenarios              |
| 4. <i>Update Systems Integration Document and Spacecraft Site Test Plan</i>   | 4. <i>Systems Integration Document, Spacecraft Site Test Plan</i> |
| 5. Finalize all system receiving, buildup, checkout, testing, launch preparation, and mission timelines/procedures                              | 5. Final Mission Operations Procedures                            |
| 6. Move all key personnel to the MCR, POCC, and DPC sites   | 6. Flight Operations Team Ready                                   |

|   |                                    |
|---|------------------------------------|
| 7. Inspect and update MCR, POCC, and DPC facilities | 7. Completed Operations Facilities |
|---|------------------------------------|

**PHASE E - PROJECT ACTIVITIES AND PRODUCTS**  
 (Systems Engineering activities shown in bold italics.)

| Activities   | Products                                    |
|--|---|
| 8. Transport all spacecraft handling and checkout equipment to the launch site   | 8. Ground Support Equipment Operations Plan |
| 9. Transport system and spacecraft to launch site  | 9. Pre-Launch Preparations Plan             |
| 10. Conduct Operational Readiness Review (ORR)   | 10. ORR Committee Report and Recommendation |
| 11. Receive system<br>11.1 Inspect<br>11.2 Buildup<br>11.3 Checkout<br>11.4 Life test  | 11. Operating System at Launch Site         |
| 12. Integrate/assemble system and spacecraft<br>12.1 Checkout<br>12.2 Test<br>12.3 Calibrate<br>12.4 Perform data flow check to POCC and DPC | 12. Operating Spacecraft at Launch Site     |
| 13. Integrate/assemble spacecraft and launch vehicle<br>13.1 Checkout<br>13.2 Verify interfaces<br>13.3 Test                                 | 13. Assembled Launch Vehicle                |
| 14. Perform data flow checks and proper communications to MCR, POCC, and DPC   | 14. Verified Data Flow                      |
| 15. Perform system maintenance as required   | 15. Pre-flight Operational Procedures       |
| 16. Conduct Flight Readiness Review (FRR)  | 16. Flight Readiness Review Report          |
| 17. Launch spacecraft<br>17.1 Countdown<br>17.2 Launch<br>17.3 Orbit insertion   | 17. Launch Procedures                       |

## **PHASE E - PROJECT ACTIVITIES AND PRODUCTS**

(Systems Engineering activities shown in bold italics.)

| Activities  | Products                                      |
|---|---|
| <b>18. Certify mission/system operational readiness</b><br>18.1 Spacecraft/system hardware/software operating properly<br>18.2 Ground hardware/software operating properly<br>18.3 Data communications functioning<br>18.4 Development Project Manager's review complete<br>18.5 POCC Team in place<br>18.6 Exceptions to any of the above evaluated and documented | 18. Mission Operational Readiness Certificate |
| <b>19. Transfer system control from MCR to POCC</b>   | 19. Mission Operational Procedures            |
| <b>20. Begin mission operations</b>   | 20. Functional System in Orbit                |
| <b>21. Establish communications between the spacecraft, POCC, and DPC</b>   | 21. Spacecraft Operational                    |
| <b>22. Determine the status of the mission and spacecraft; evaluate the effects of anomalies on the experiment:</b><br>22.1 Operations<br>22.2 Data Products<br>22.3 Schedules, and so forth  | 22. Mission Verification                      |
| <b>23. Establish workaround plans for all known anomalies</b>   | 23. Mission Recovery Plans and Procedures     |
| <b>24. Perform the experiment operations start-up procedure</b>   | 24. Experiment Operational                    |
| <b>25. Carry out the experiment real-time life and health test</b>  | 25. Experiment Verification                   |
| <b>26. Perform scheduled flight operations as planned</b>   | 26. Flight Operations Procedures              |
| <b>27. Conduct Operational Acceptance Review (Post-flight Review)</b>   | 27. Post-flight Review Report                 |
| <b>28. Start mission science and engineering continuous data trending</b>   | 28. Data Operations Procedures                |
| <b>29. Resolve experiment anomalies; establish and execute contingency operating plans as needed</b>  | 29. Experiment Recovery Plans and Procedures  |
| <b>30. Manage allocation of spacecraft resources</b>  | 30. Flight Operations                         |

**PHASE E - PROJECT ACTIVITIES AND PRODUCTS**  
 (Systems Engineering activities shown in bold italics.)

| Activities   | Products                          |
|--|-----------------------------------|
| 31. Generate scheduled and special mission reports   | 31. Mission Reports               |
| 32. Generate the experiment science and technology data<br>32.1 Raw data<br>32.2 Calibrated data<br>32.3 Engineering data<br>32.4 Science data   | 32. Data Reports                  |
| <i>33. Validate data</i>   | <i>33. Data Validation Report</i> |
| 34. Monitor the engineering performance of the spacecraft and the experiment   | 34. Flight Operations             |
| 35. Perform system maintenance as needed   | 35. Flight Operations             |
| 36. Accomplish planned data distribution   | 36. Data Operations Procedures    |
| 37. Conduct ongoing mission operations performance evaluations   | 37. Flight Operations             |
| 38. Conduct missions final engineering test and generate test report   | 38. Engineering Test Report       |
| 39. Terminate mission<br>39.1 Perform final data processing<br>39.2 Terminate flight operations according to plans<br>39.3 Shut down the communications network<br>39.4 Shut down ground operations elements | 39. Mission Termination           |
| 40. Recover spacecraft and experiment if applicable  | 40. Recovery Operation            |
| 41. Deliver recovered data (tapes, memory, disk, and so forth) to DPC  | 41. Recovery Operation            |
| 42. Deliver flight hardware to cognizant authorities for disposition/storage   | 42. Recovery Operation            |

## PHASE E - PROJECT ACTIVITIES AND PRODUCTS

(Systems Engineering activities shown in bold italics.)

| Activities   | Products  |
|--|---|
| 43. Create Post Mission Evaluation Report<br>43.1 Show validation of requirements<br>43.2 State overall system performance<br>43.3 Evaluate the effects of anomalies<br>43.4 Discuss lessons learned | 43. <i>Mission Evaluation Report</i>  |
| 44. Conduct Lessons Learned Review (LLR)   | 44. Lessons Learned Report  |
| 45. Continue science and engineering data reduction  | 45. Data Operations Plan  |
| 46. Implement Pre-Planned Product Improvement (P3I) if applicable  | 46. Refurbish and Modify Equipment  |
| 47. Consider Next Operational Concept (NOC)  | 47. Follow-on Proposal; Restart Systems Engineering Process at Requirements Definition and Conceptual Trade Studies - Phase A |

## LESSONS LEARNED

### SUMMARY

This Chapter contains information and experience gained through application of systems engineering at Langley Research Center.

#### 7.1 INTRODUCTION

Information in this Chapter was compiled from experience with application of the systems engineering process at Langley Research Center (LaRC). Observations are listed point by point and this Chapter will be expanded as more information becomes available. Note that the systems engineering database will contain lessons learned information.

#### 7.2 COMMUNICATION

The importance of good communications cannot be overstressed. The systems engineer must verify that mechanisms are in place to assure that all team members are in close contact with one another. The most critical aspect of this task is the communication of the customer's needs and goals to the rest of the team. Likewise, frequent briefings to management of the sponsoring organization are extremely helpful in keeping the project on track. A thorough understanding must be maintained by the subsystem managers of not only their own requirements, but also of the relationships existent with other sub-systems. Regular team meetings are strongly indicated to facilitate good communication. In addition, the systems engineer must pay careful attention to those related team members whom should communicate frequently because of closely correlated subsystems, and ensure that regular interchanges occur. This aspect of the process must be exercised for local as well as off site team members.

#### 7.3 FORMULATION STUDY STAFFING

In Pre-Phase A and Phase A, resources are usually provided by the sponsoring organization. Typically, the resources will be very limited, if they exist at all. Likewise, study team members will be participating in the study in addition to their regular duties. Often, a meeting of all team members will be difficult to schedule without a long lead-time. This makes the job of the systems engineer especially challenging if the study is to be performed in a timely manner. A proactive Study Manager is helpful, but ultimately, the systems engineer must gather information for systems analyses from all participating team members. There are three approaches that the systems engineer may take to address this situation.

First, it is a very good idea to establish a routine team meeting date at the very beginning of the study, such as "every Wednesday at 3 p.m." Next, tools should be used to maximize the efficiency of the information captured during these meetings. Tape or video recorders, electronic copy boards, and cameras can be invaluable in ascertaining what was said or meant in a meeting. This allows the systems engineer to review meetings for detail, without having to re-contact participants. This is also very helpful in recording decisions for the audit trail. Finally, the systems engineer should frequently visit the other team members as necessary to retrieve information needed for analysis. Taken together, these three steps can significantly decrease the time required for formulation studies.

#### 7.4 AUDIT TRAIL

Maintenance of good project records is advisable for several reasons. First of all, a good audit trail can be invaluable when quick justification for decisions is required. This can be especially valuable when contractor disputes or grievances arise. Also, complete and well organized records can prevent duplication of effort by the project team. Finally, the information serves as a project archive that may be utilized as a reference for future endeavors and for generation of lessons learned. The audit trail is essentially the information stored as the project data base and includes such items as: conceptual layouts, schematics, meeting minutes, analysis summaries and results, correspondence, schedules, and the typical information stored on the system configuration. Establishment and maintenance of the project audit trail is a prime responsibility of systems engineering, since much of the critical information is generated by that function.

#### 7.5 RESOURCE BUDGET RESERVES

The nature of research projects is one of uncertainty, since most undertakings have never before been accomplished. Thus, risk is inherent in LaRC project development, and planning for the unexpected is necessary. One method of planning for the unforeseen is to hold a significant portion of system resources in reserve in the early stages of the project. After the baseline concept is established, system commodities such as weight and power must be allocated to the control of subsystem managers by the systems engineer. While no exact numbers are available, experience has shown that budget reserves of 30 percent or so are well advised in the Preliminary Design Review (PDR) time frame of a project. This value should be varied according to the risk associated with a given development. For example, a well characterized, second generation system may require only a 10 percent budget reserve at PDR. Conversely, a project breaking new technological ground may need 40 percent at this stage. Some reserve should be held even at the system Critical Design Review (CDR) to deal with uncertainties through the fabrication and assembly process. Reserves in the 10 percent range are typically sufficient for an average LaRC project at CDR. Even with these margins, the Project Manager and the systems engineer must be frugal in the release

of reserves, to prevent abuse of the process. Subsystem projections should be studied carefully to assure that resource requirements are realistic, and not underestimated because of an understanding that additional resources are available for the asking.

**Continue to Next Section**