System Phases, Modes, and States

Solutions to Controversial Issues

Charles S. Wasson, Author

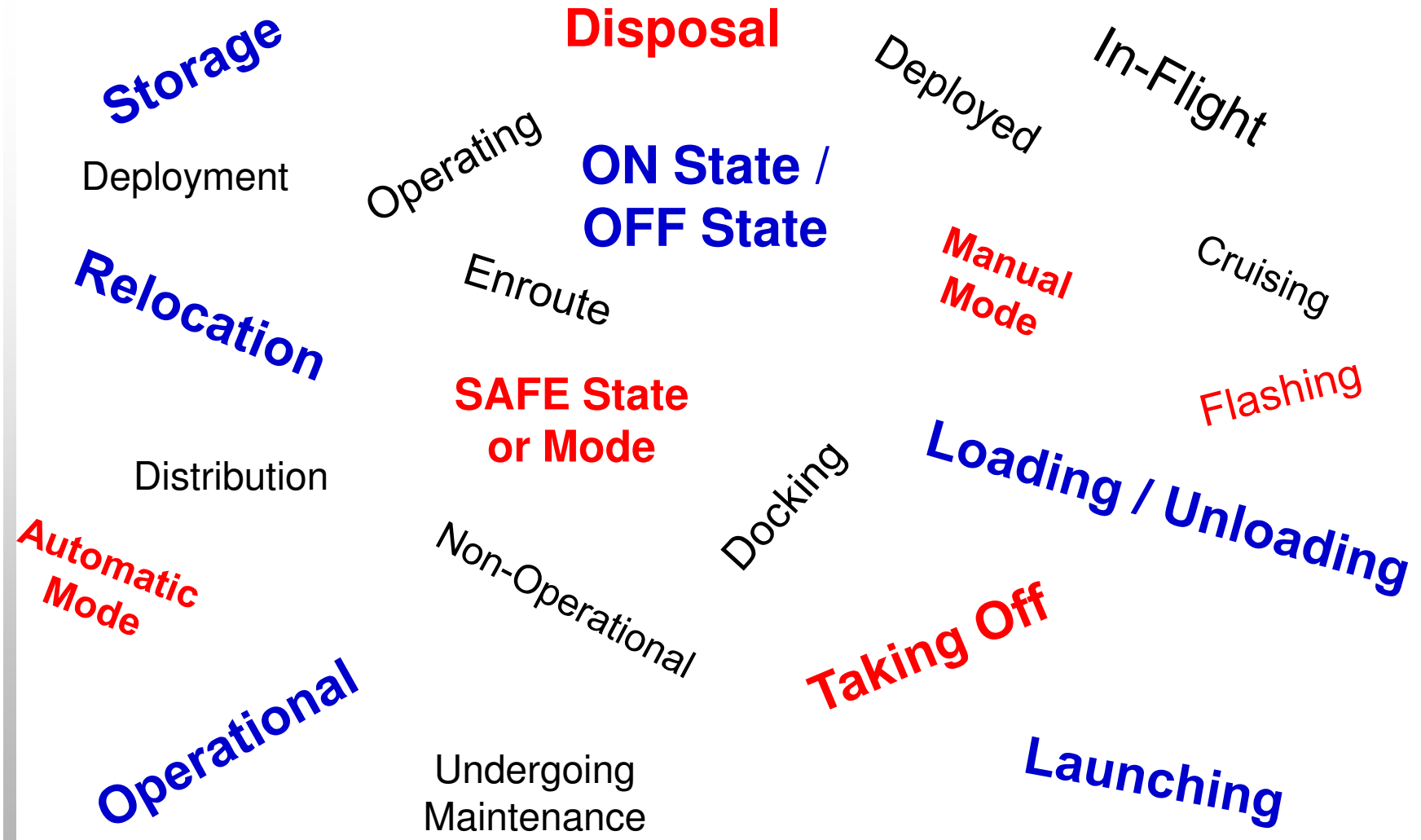
System Analysis, Design, and Development

Wasson Strategics, LLC

www.wassonstrategics.com

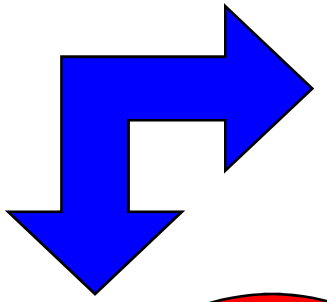
Framing the Problem Space

One Person's "Mode" = Another Person's "State"



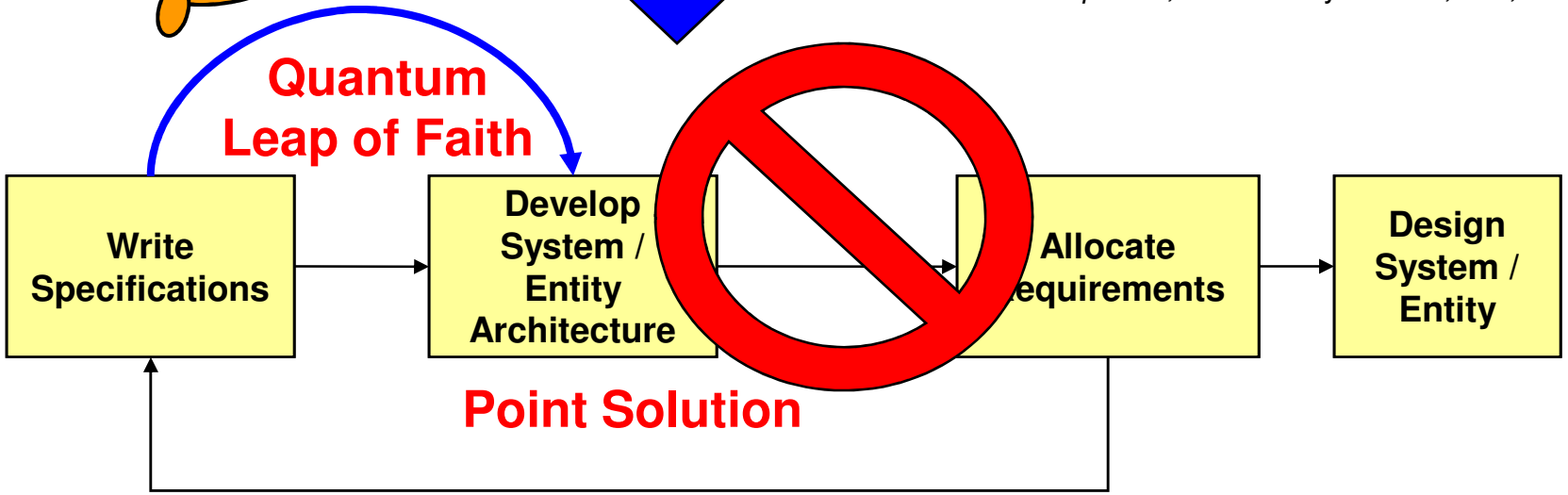
Common SE Development Paradigm

- **Organizations often make bold proclamations of performing SE. Then, naively and erroneously perceive its implementation as follows:**

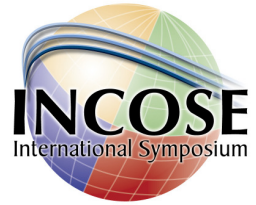


Four Domain Solutions*
- Requirements Architecture
- Operational Architecture
- Behavioral Architecture
- Physical Architecture

* Wasson, Charles S., *System Analysis, Design, and Development*, John Wiley & Sons, Inc., 2006.



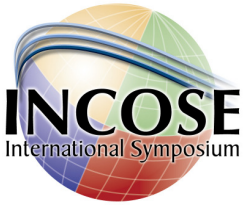
Statement of the Problem



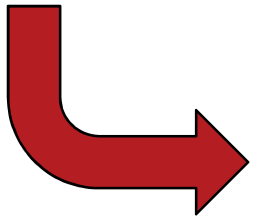
- ***System development activities often inefficiently waste critical project resources and ineffectively architect systems due to a lack of knowledge in how to properly apply system phases, modes, and states of operation.***

- **Objective Evidence of the Problem**
  - Project teams and team members become mired in controversy due to misguided / inexperienced leadership concerning how a system, product, or service is envisioned to be:
    - Operationally deployed, operated, sustained, and disposed.
    - Conceptualized, structured, and organized to support the preceding item.

MIL-STD-498 (Cancelled) SW DID Guidance (1 of 2)



- **3.1 Required states and modes.**
  - If the system is required to operate in more than one state or mode having requirements distinct from other states or modes, this paragraph shall identify and define each state and mode.
  - Examples of states and modes include: idle, ready, active, post-use analysis, training, degraded, emergency, backup, wartime, peacetime.
  - The distinction between states and modes is arbitrary. A system may be described in terms of states only, modes only, states within modes, modes within states, or any other scheme that is useful.



Source: MIL-STD-498 DID for *System / Subsystem Specification* DI-IPSC-81431A, p.3.

Internet Example (1 of 2)

- **The operating system can be in one of four states:**
  - *Executing in user mode*
  - *Executing in system mode*
  - *Idle waiting for I/O*
  - *Idle*

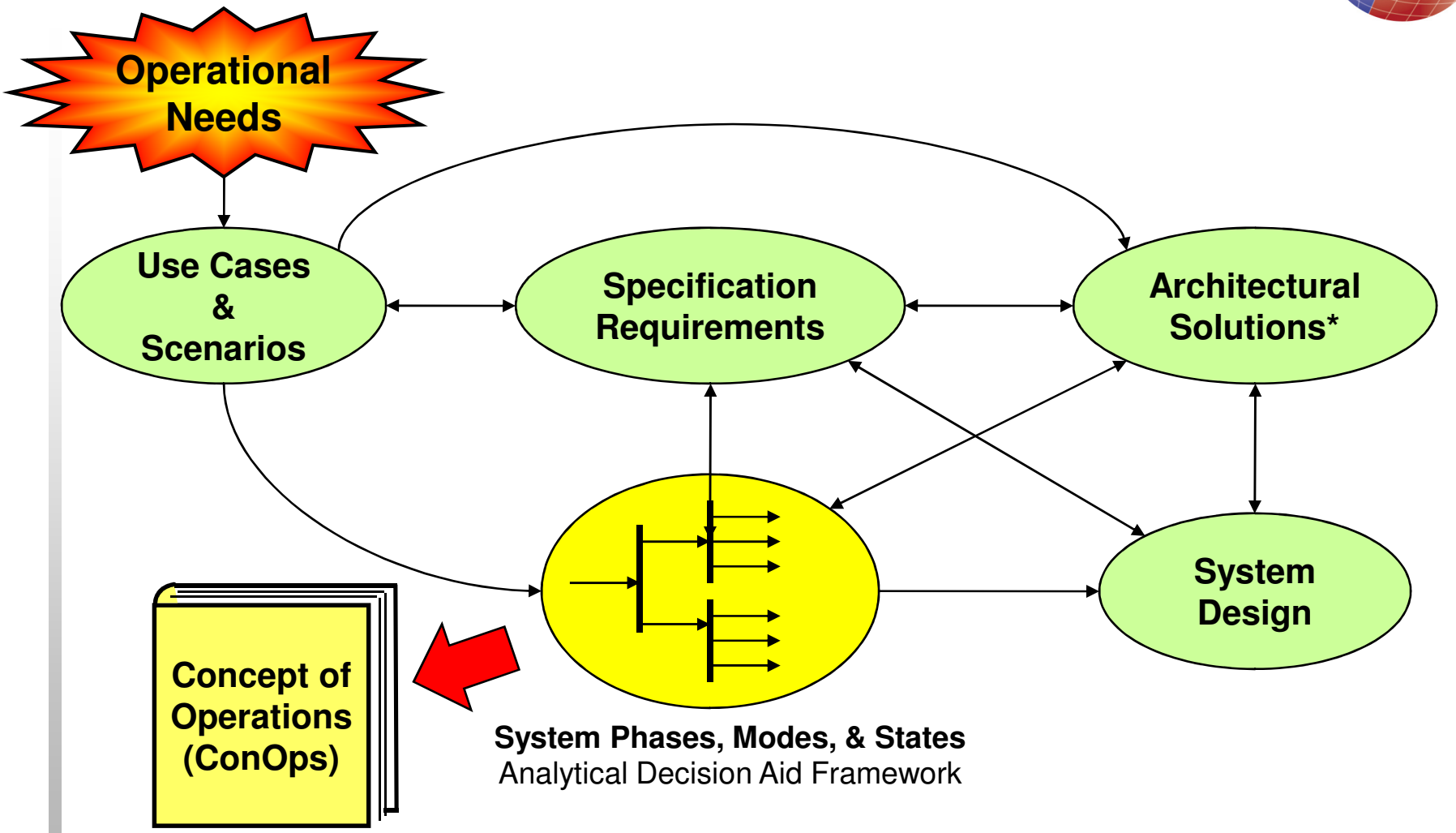
States???

Source: SCO OpenServerTM documentation set.osr507doc.sco.com/en/PERFORM/OS_states.html

Sources of the Problem

- **The major factors driving misunderstandings of phases, modes, and states are the lack of:**
  - Formal engineering education including SE, training, and knowledge framework and leadership for project teams.
  - Professional standards governing definition of states and modes.
  - Organizational standard processes (OSPs) prepared by experienced and knowledgeable professionals.

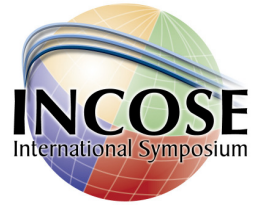
Understanding the Role of Modes & States in SE



* Wasson, Charles S., *System Analysis, Design, and Development*, John Wiley & Sons, Inc., 2006.

Central Issues
Underlying the Application of Modes & States

Central Issues Driving the Controversy



- **Issue #1**
  - *What is the difference between Modes and States?*
- **Issue #2**
  - *Do modes contain states or do states contain modes?*
- **Issue #3**
  - *Should specifications explicitly specify M & S requirements?*
- **Issue #4**
  - *Should M & S requirements be flowed down to lower level architectural elements?*

Issue #1
What is the Difference between Modes and States?

Literature Survey of "State" Definitions

Source	Definition
INCOSE Handbook v3.2 [4]	No definition provided.
Wasson [5]	**State** - The operational or operating condition of a SYSTEM OF INTEREST (SOI) required to safely conduct or continue its mission.
IEEE 610.12-1990 [6]	**State** - "A condition or mode of existence that a system, component, or simulation may be in; for example, the pre-flight state of an aircraft navigation program or the input state of given channel."
SMC System Engineering Primer & Handbook [7]	**State** – "The condition of a system or subsystem when specific modes or capabilities (or functions) are valid. The document provides the following examples: "Off, Start-up, Ready On, Deployed, Stored, In-Flight, etc."
Buede [8]	**State** – "The *state of a system* is commonly defined to be a static snapshot of the set of metrics needed to describe fully the system's capabilities to perform the system's functions. The system is progressing through a constantly changing series of state as time progresses."
Unmanned Systems Safety Guide [9]	**State** - States identify conditions in which a system or subsystem can exist … A system or subsystem may be in only one state at a time. States are unique and may be binary (i.e., they are either true or not true) … A state is a subset of a mode."

Literature Survey of "State" Definitions

Source	Definition
INCOSE Handbook v3.2 [4]	No definition provided.
Wasson [5]	**State** - The operational or operating condition of a SYSTEM OF INTEREST (SOI) required to safely conduct or continue its mission.
IEEE 610.12-1990 [6]	**State** - "A condition or mode of existence that a system, component, or simulation may be in; for example, the pre-flight state of an aircraft navigation program or the input state of given channel."
SMC System Engineering Primer & Handbook [7]	**State** – "The condition of a system or subsystem when specific modes or capabilities (or functions) are valid. The document provides the following examples: "Off, Start-up, Ready On, Deployed, Stored, In-Flight, etc."
Buede [8]	**State** – "The *state of a system* is commonly defined to be a static snapshot of the set of metrics needed to describe fully the system's capabilities to perform the system's functions. The system is progressing through a constantly changing series of state as time progresses."
Unmanned Systems Safety Guide [9]	**State** - States identify conditions in which a system or subsystem can exist … A system or subsystem may be in only one state at a time. States are unique and may be binary (i.e., they are either true or not true) … A state is a subset of a mode."

Literature Survey of "Mode" Definitions

Source	Definition
INCOSE Handbook v3.2 [4]	**Mode** - No definition provided.
Wasson [10, 11]	**Mode of Operation** - "An abstract label applied to a collection of system operational capabilities and activities focused on satisfying a specific phase objective. [10]… A Mode of Operation represents a User (Actor) selectable option that requires the integrated HUMAN-MACHINE performance of a set of task sequences that accomplish the phase / sub phase objectives." [11]
SMC System Engineering Primer & Handbook [12]	**Mode** - The condition of a system or subsystem in a certain state when specific capabilities (or functions) are valid. Each mode may have different capabilities defined." … "modes" within the READY state: Normal, Emergency, Surge, Degraded, Reset, etc."
Unmanned Systems Safety Guide [13]	**Mode** - "Modes identify operational segments within the system lifecycle generally defined in the Concept of Operations. … Modes consist of one or more sub-modes. … A system may be in only one mode, but may be in more than one sub-mode, at any given time."
IEEE 1220 610.12-1990 [14]	**Mode** - "An operating condition of a function or sub-function or physical element of the system."
Buede [15]	**Mode** – "A system *mode* is a distinct operational capability of the system; this capability may use either the full or partial set of the system's functions."

Literature Survey of "Mode" Definitions

Source	Definition
INCOSE Handbook v3.2 [4]	**Mode** - No definition provided.
Wasson [10, 11]	**Mode of Operation** - "An abstract label applied to a collection of system operational capabilities and activities focused on satisfying a specific phase objective. [10]… A Mode of Operation represents a User (Actor) selectable option that requires the integrated HUMAN-MACHINE performance of a set of task sequences that accomplish the phase / sub phase objectives." [11]
SMC System Engineering Primer & Handbook [12]	**Mode** - The condition of a system or subsystem in a certain state when specific capabilities (or functions) are valid. Each mode may have different capabilities defined." … "modes" within the READY state: Normal, Emergency, Surge, Degraded, Reset, etc."
Unmanned Systems Safety Guide [13]	**Mode** - "Modes identify operational segments within the system lifecycle generally defined in the Concept of Operations. … Modes consist of one or more sub-modes. … A system may be in only one mode, but may be in more than one sub-mode at any given time."
IEEE 1220 610.12-1990 [14]	**Mode** - "An operating condition of a function or sub-function or physical element of the system."
Buede [15]	**Mode** – "A system *mode* is a distinct operational capability of the system; this capability may use either the full or partial set of the system's functions."

Delineating Definitions - Modes Versus States

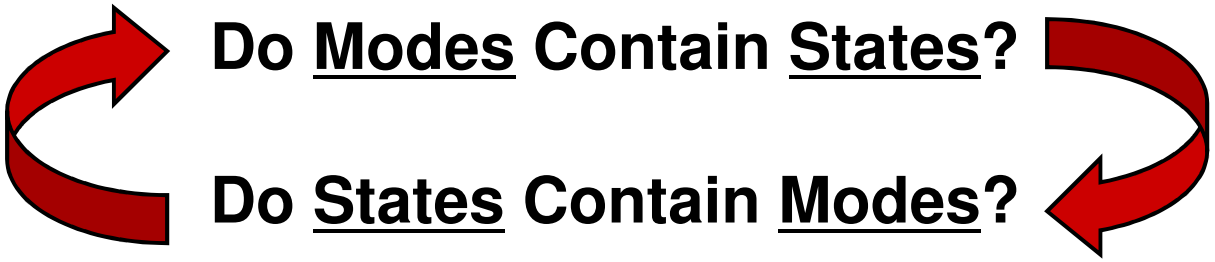
- **State**
  - An attribute used to characterize the current logistical employment, status, or performance-based condition of a system, product, or service or system components at the element, subsystem, assembly, subassembly, etc. levels of abstraction.

Delineating Definitions - Modes Versus States

- **State**
  - An attribute used to characterize the current logistical employment, status, or performance-based condition of a system, product, or service or system components at the element, subsystem, assembly, subassembly, etc. levels of abstraction.

- **Mode**
  - An abstract label applied to a user selectable option that enables a set of use case-based system capabilities to be employed in conjunction with organizational processes and procedures to command and control (C2) a system, product, or service to achieve a specified set of mission objectives, outcomes, and levels of performance.
    - Triggering events serve as entry and exit criteria for transitioning into and out of a mode.
    - Modes can have sub-modes.

Issue #2

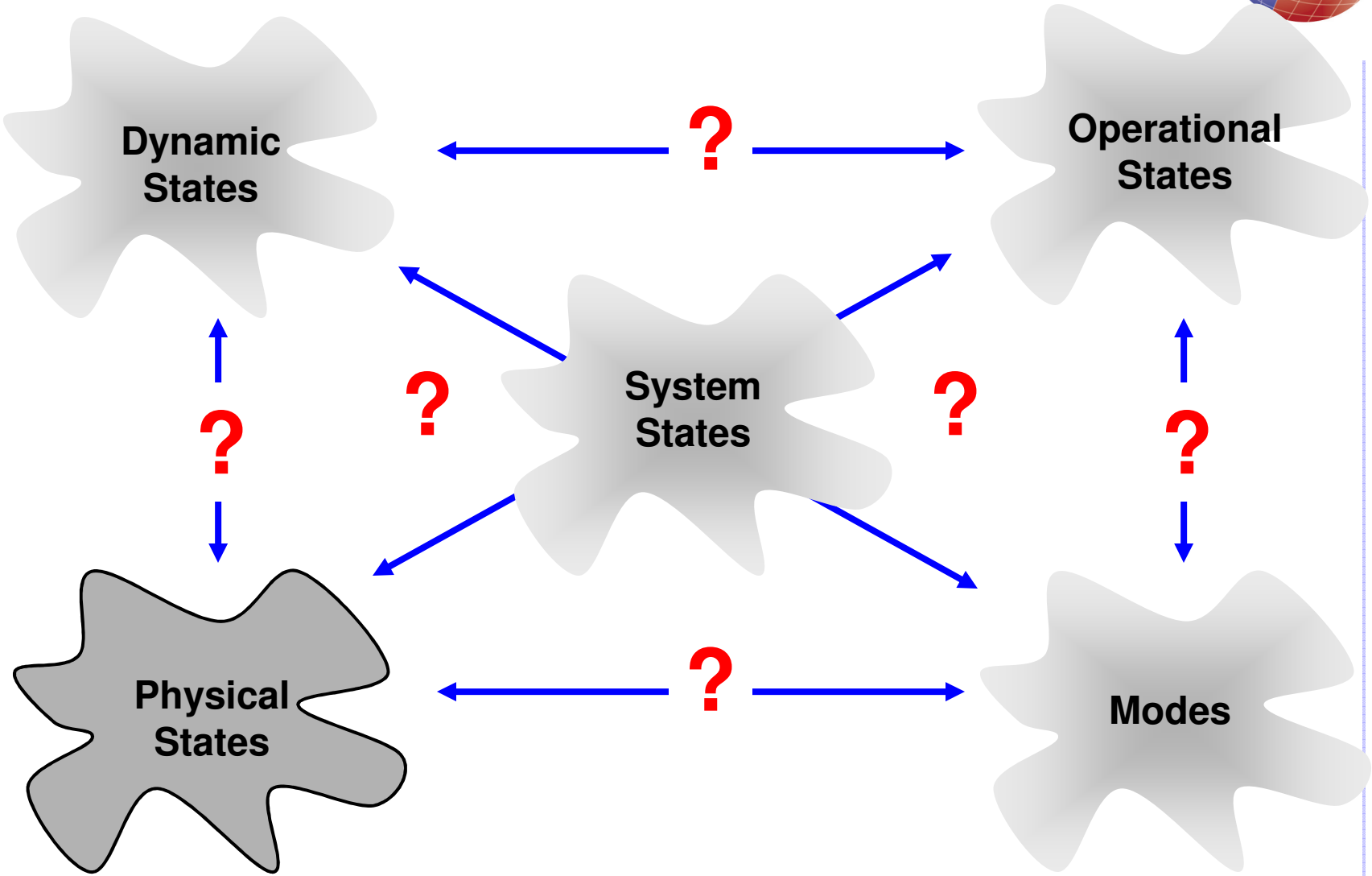


The Answer May Surprise You

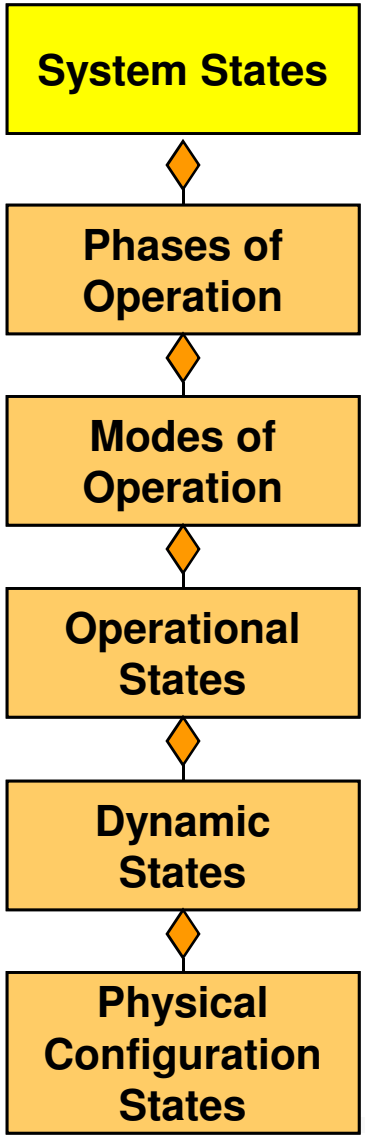
Four Types of States

- **System owners, users and end users, project managers, et al frame of reference:**
  - Current state of employment of an organizational asset to perform mission(s). → **System States**
  - Current state of mission readiness → **Operational States**
- **Engineering frame of reference: :**
  - Operating condition or status → **Operational States**
  - Dynamics (behavioral characteristics) → **Dynamic States**
  - Physical configuration → **Physical States**

Defining Interrelationships Between States



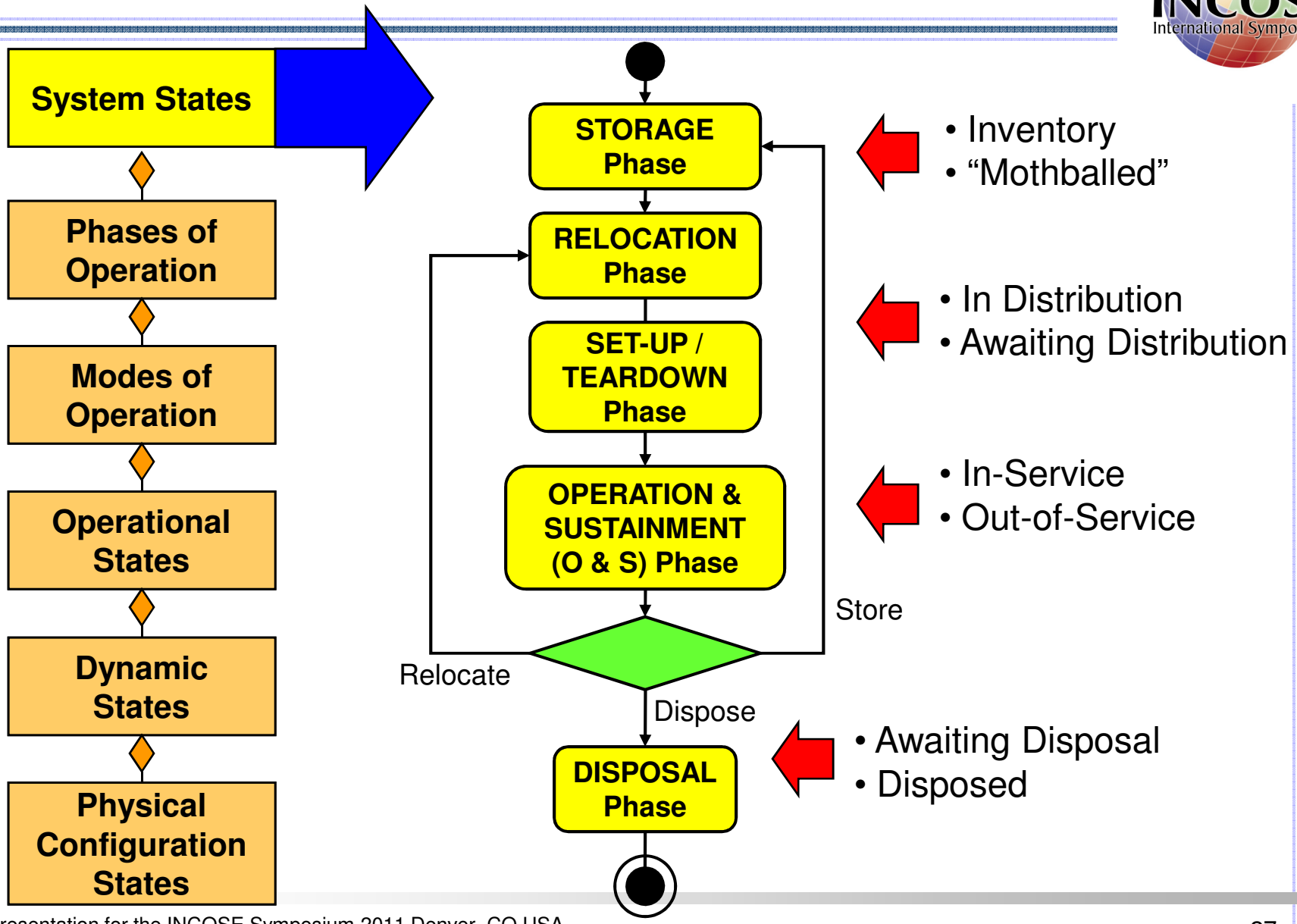
System States



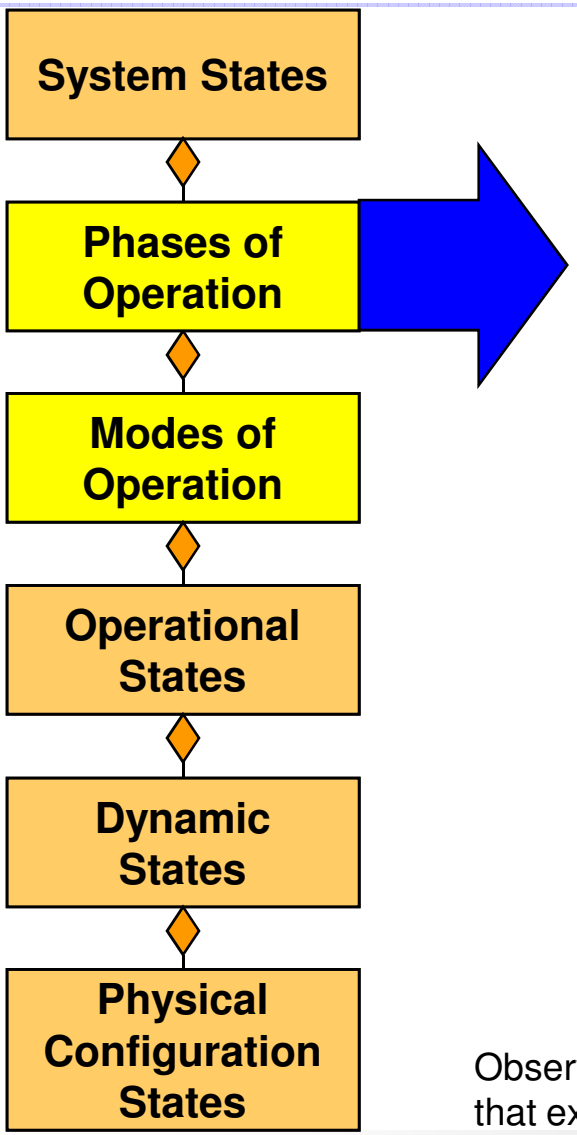
System State

An attribute that indicates the logistical employment, availability, or condition of an organizational asset such as a system, product, or service.

System States



Example - System Modes By Phase of Operation

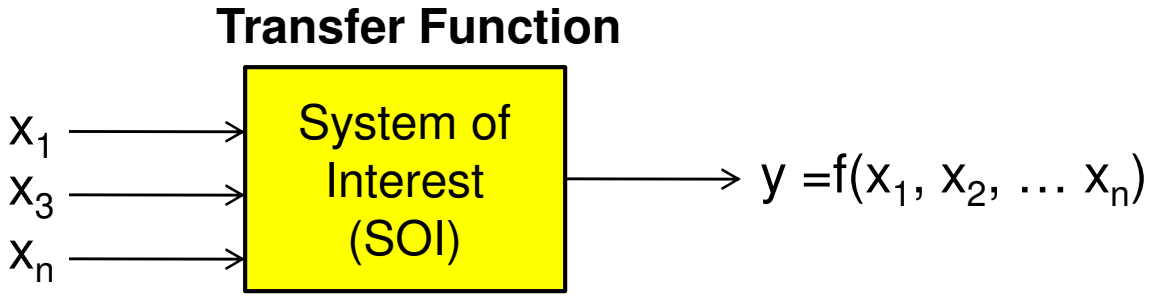


- **Pre-Mission Phase**
  - Power-Up / Initialization Mode
  - Calibration / Alignment Mode
  - Configuration Mode
  - Training Mode
- **Mission Phase**
  - Manual Mode (Generic)
  - Automatic Mode (Generic)
  - Training Mode
- **Post-Mission Phase**
  - Safe Mode
  - Maintenance Mode
  - OFF Mode

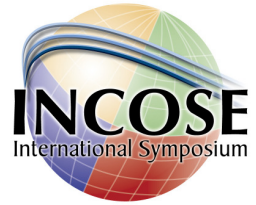
Observe that Phases and Modes establish an analytical framework that exhibits objective –based outcomes to be achieved.

Modes as Abstract Labels

- **Modes, as abstract labels, enable humans to leverage system capabilities to achieve phase-based objectives.**
- **As inanimate objects with stimulus-behavioral response transfer functions, systems are clueless about human "modes" …**
- **… However, what systems do understand (by design) is the need to respond to specific types of inputs and produce / exhibit patterns of behavior**

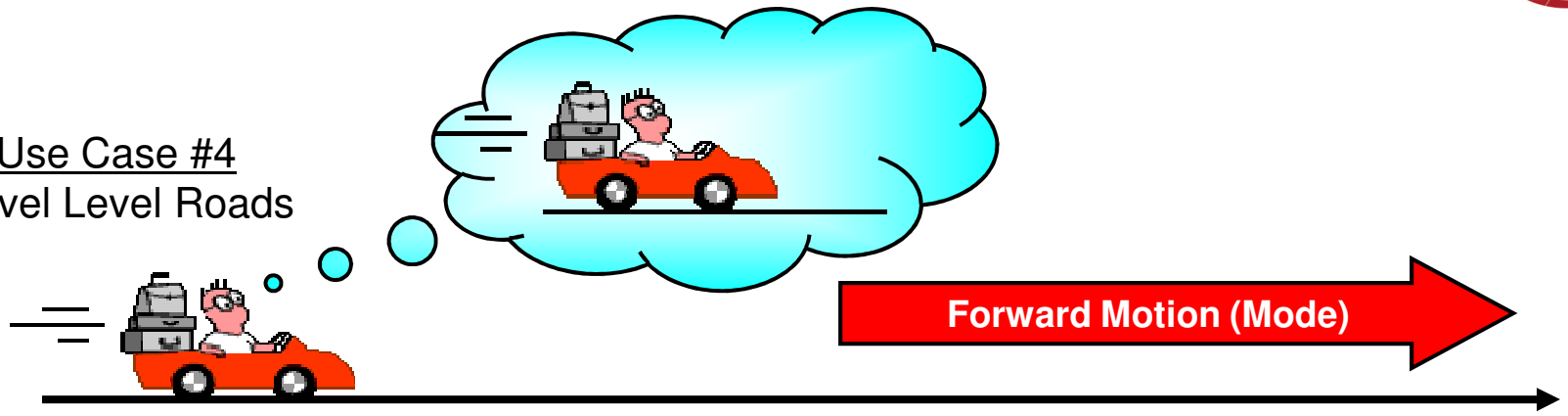


Car Modes as Abstract Labels (1 of 5)



- **Park (Stationary) Mode**
  - Use Case #1 – Safely Idle in Place
- **Neutral Mode**
  - Use Case #2 – Idle Unconstrained
- **Reverse (Direction) Mode**
  - Use Case #3 –Move Backward
- **Forward (Direction) Mode**
  - Use Case #4 – Travel on Level Ground
  - Use Case #5 – Climb Moderate Inclines
  - Use Case #6 – Climb Steep Inclines

Car Modes as Abstract Labels (2 of 5)



Control Stimuli

Behavioral Response(s)

Human Inputs

- "DRIVE"
- Accelerator
- Brake
- Steering

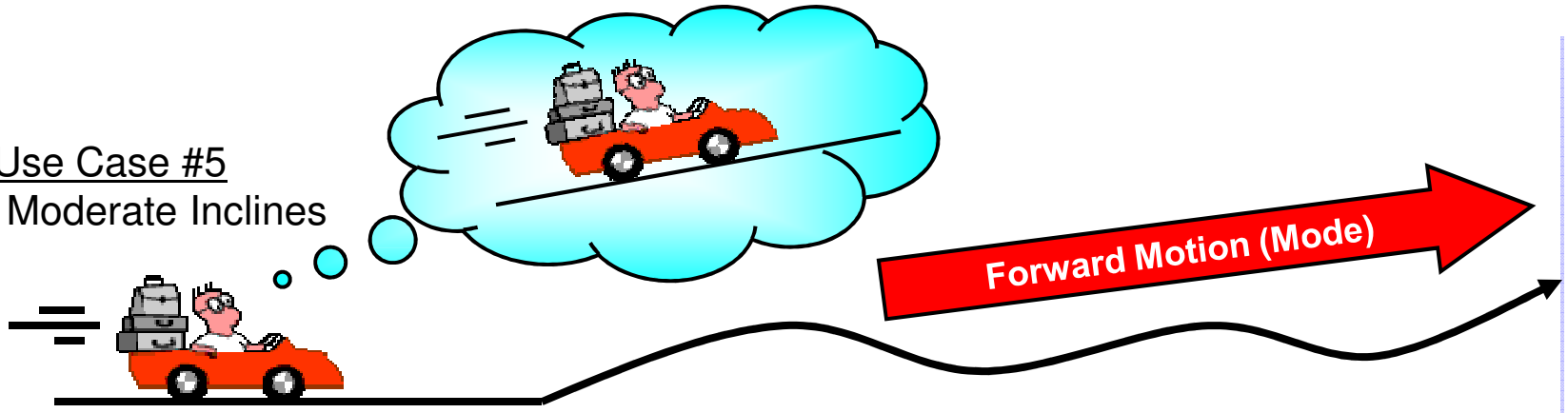
Car System

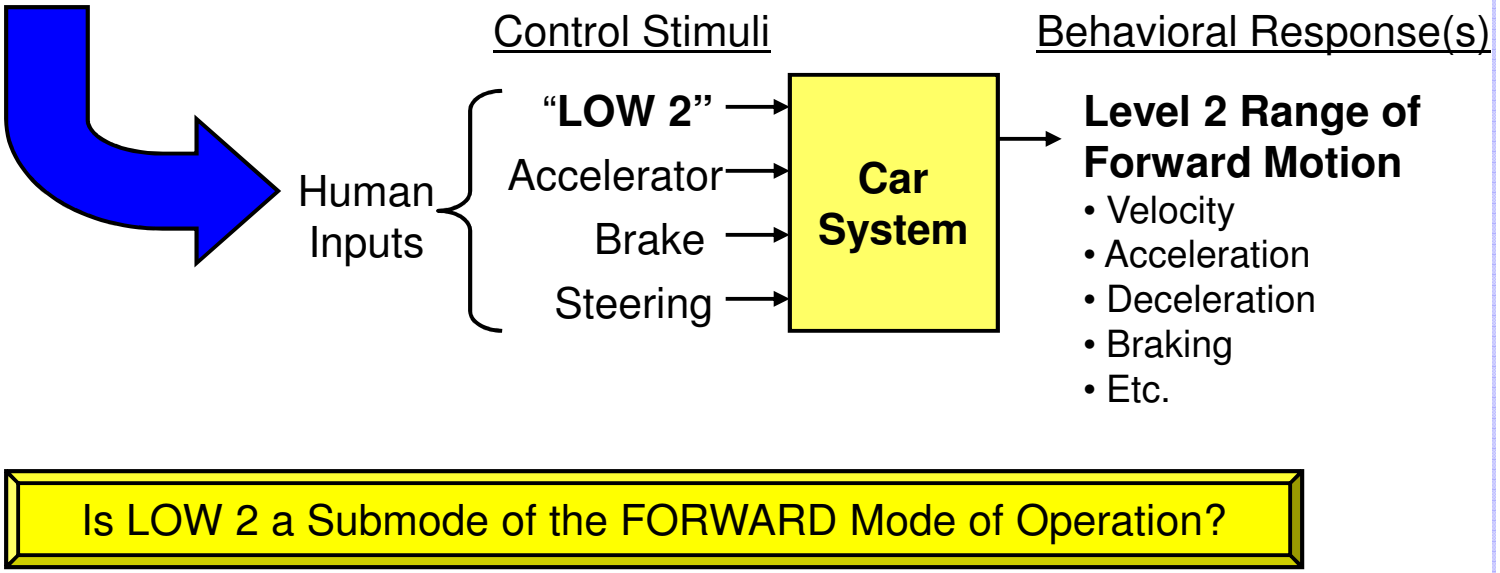
Level 3 Range of Forward Motion

- Velocity
- Acceleration
- Deceleration
- Braking
- Etc.

Is DRIVE a Submode of the FORWARD Mode of Operation?

Car Modes as Abstract Labels (3 of 5)





Is LOW 2 a Submode of the FORWARD Mode of Operation?

Car Modes as Abstract Labels (4 of 5)

Control Stimuli

Behavioral Response(s)

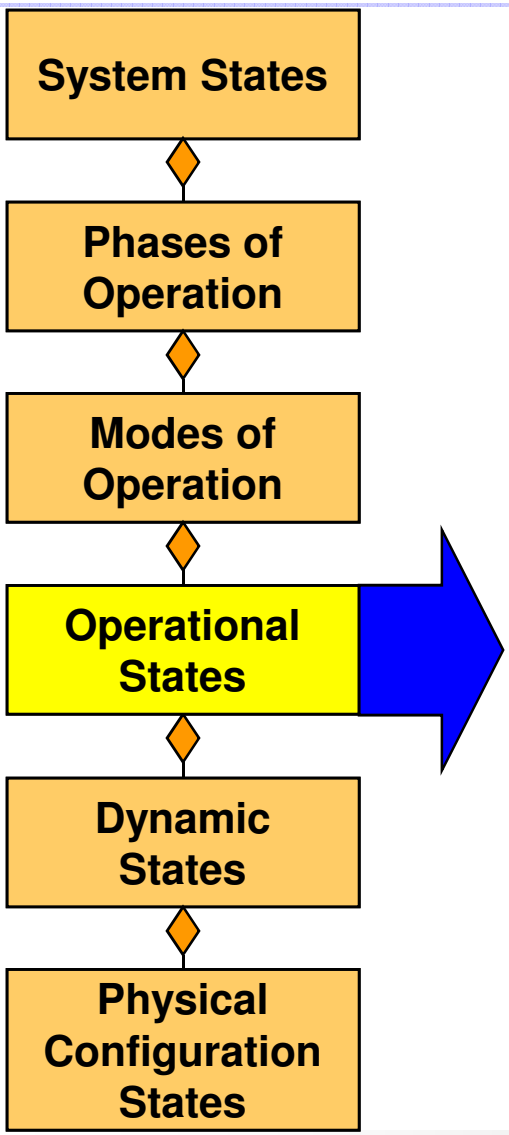
Human Inputs
- "LOW 1"
- Accelerator
- Brake
- Steering

→ **Car System** →

Level 1 Range of Forward Motion
- Velocity
- Acceleration
- Deceleration
- Braking
- Etc.

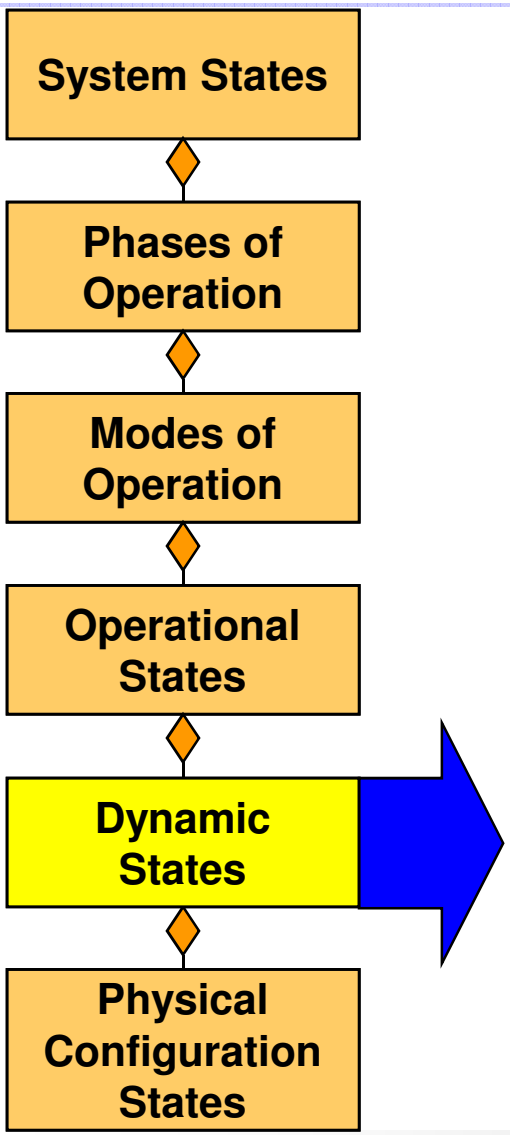
Is LOW 1 a Submode of the FORWARD Mode of Operation?

Definition - Operational State



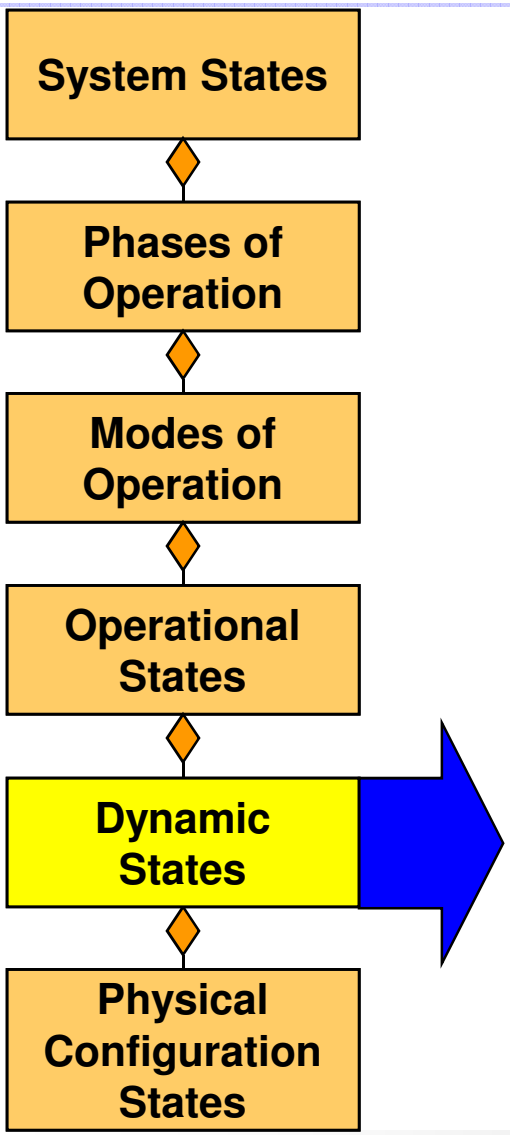
- **Operational State**
  - An attribute that represents the condition – e.g., level of activation - of a system, product, or service to conduct missions. For example:
    - ON / OFF
    - Operational / Non-Operational
    - (Site) Activated / Deactivated
    - Degraded Performance
    - Standby
    - Etc.

Definition - Dynamic States



- **Dynamic State**
  - An attribute that characterizes the time-dependent rate of change – e.g., attitude, motion, mass properties, or performance - of a system or product relative to a frame of reference and prescribed operating environment conditions.
  - Dynamic States typically have an "ing" suffix – e.g., initializing, accelerating, melting, landing, etc.

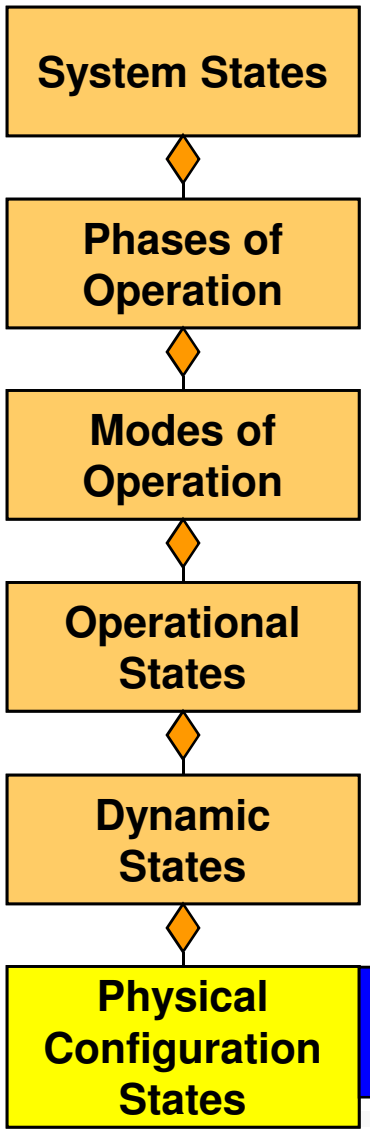
Dynamic States – Free Versus Fixed Bodies



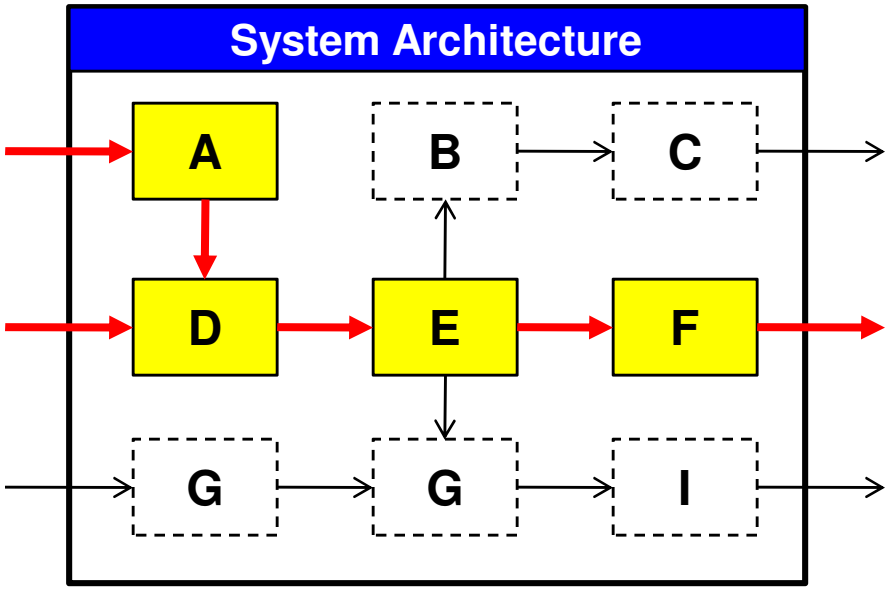
- **Free Body in Space – Dynamic States**
  - Navigating
  - Launching
  - Docking
  - Landing
  - Maneuvering, etc.

- **Fixed Bodies – Dynamic States**
  - Idling
  - Processing
  - Storing
  - Communicating
  - Updating, etc.

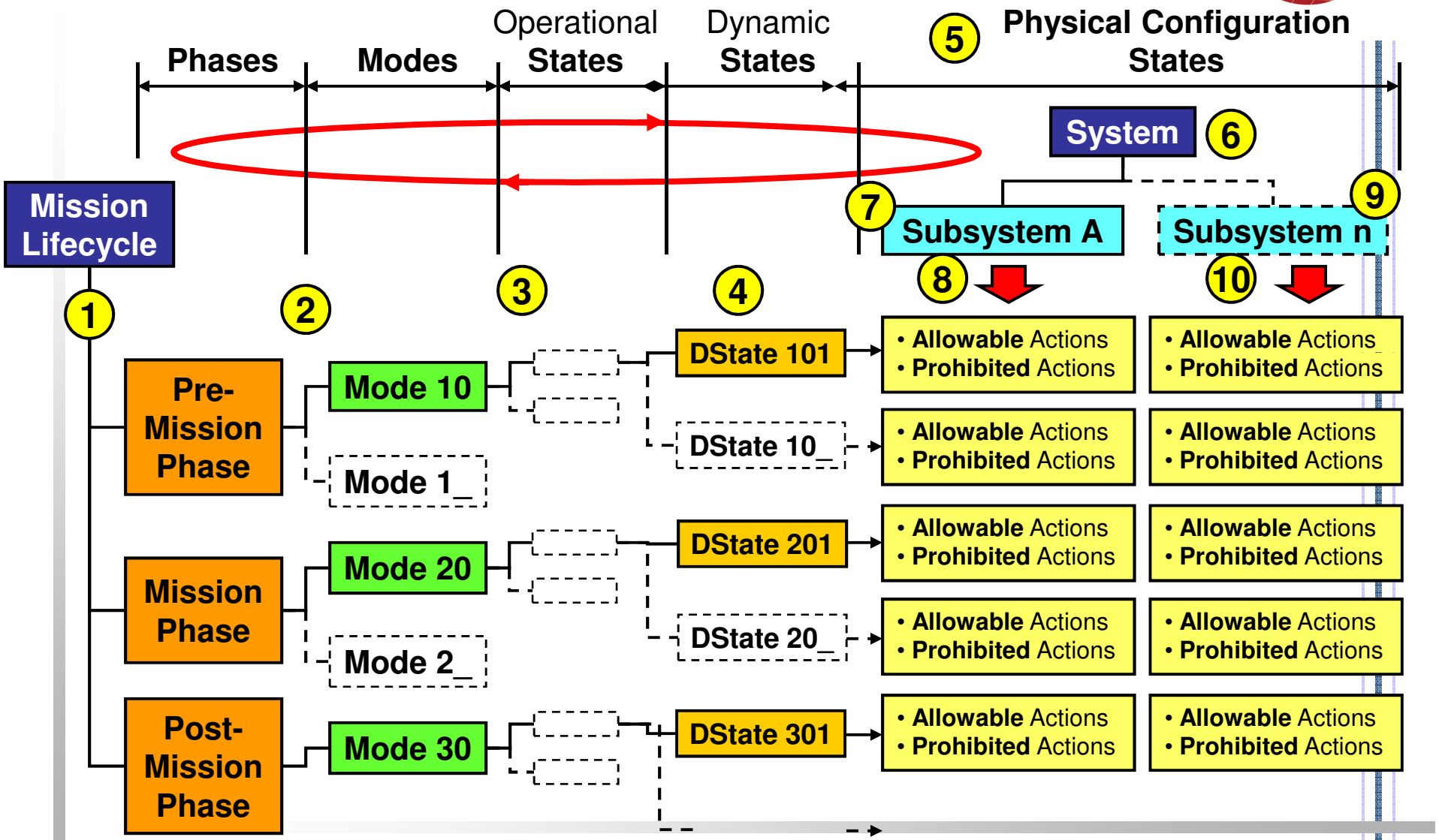
Definition – Physical Configuration States



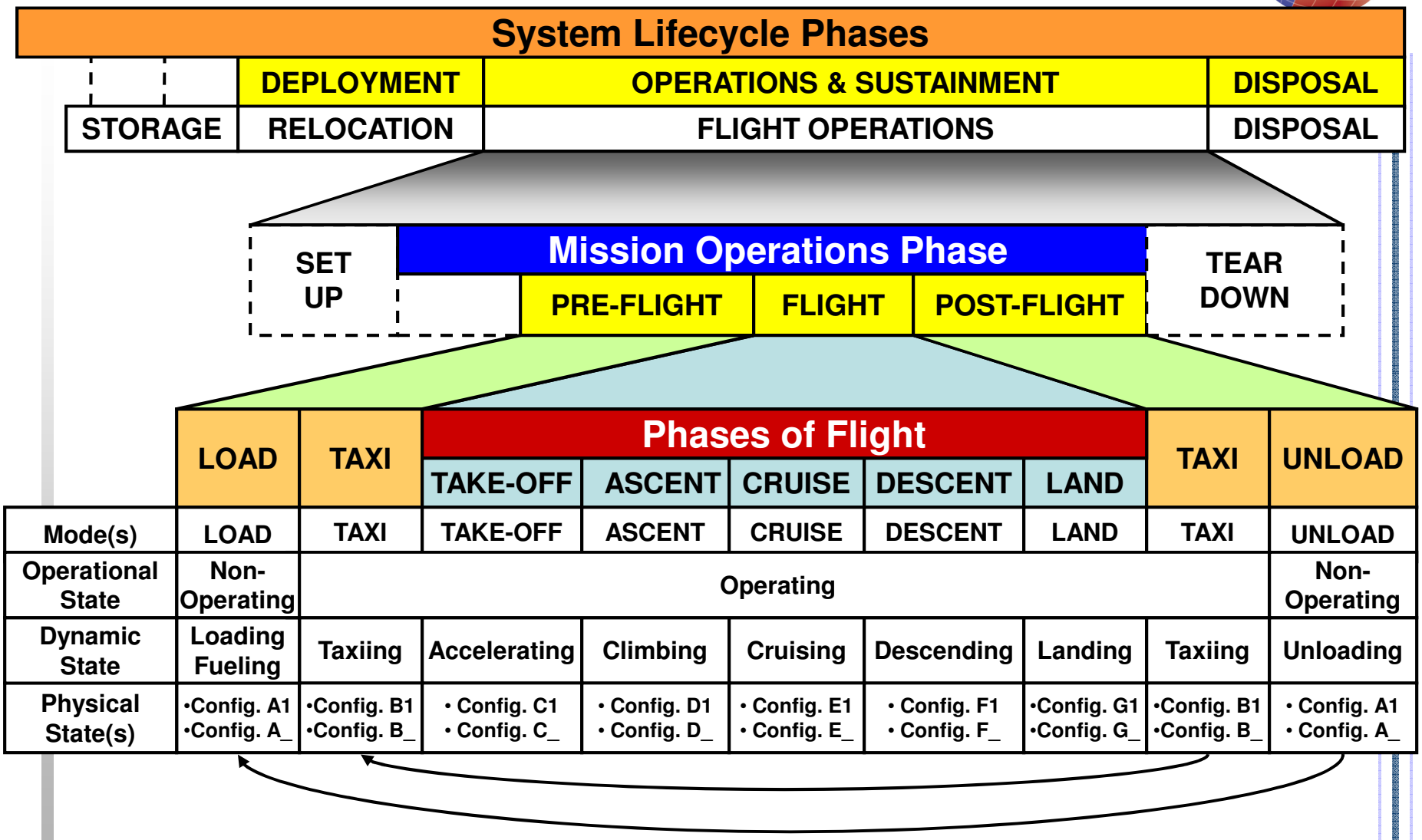
- **Physical Configuration State**
  - An attribute that characterizes the physical arrangement – i.e., configuration – of a system, product, or service's architectural elements required to enable a user to achieve one or more Mode or use case- based objectives and levels of performance.



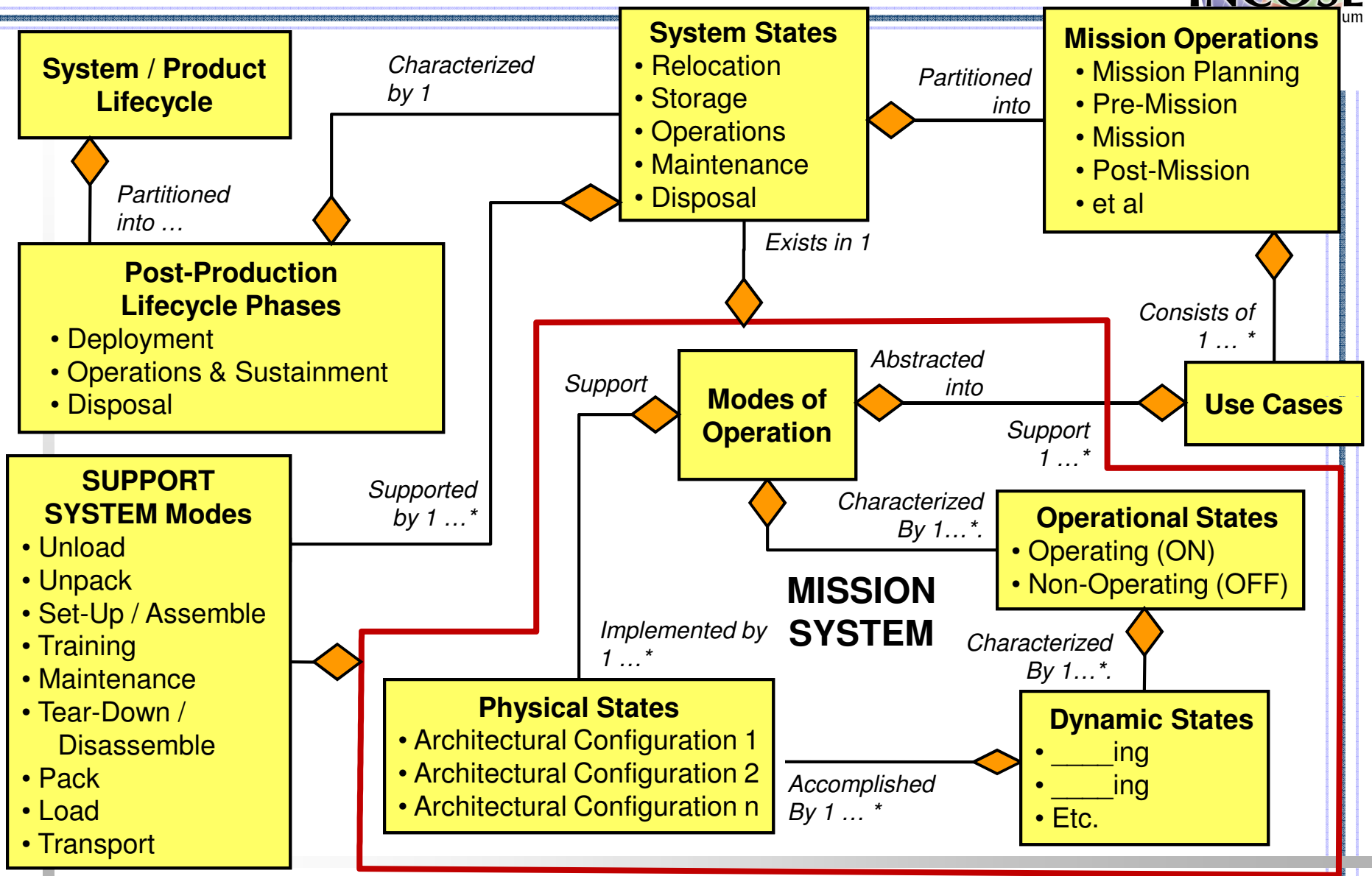
Modes & States Command & Control (C2)



Example - Aircraft System Phases, Modes, & States



Phase of Operation Perspective ER Diagram



Issue #3
Should Specifications Contain Modes & States Requirements?

States & Modes in Specifications

- **"3.2.1 Performance Characteristics**
  - 3.2.1.1 State 1 Name
    - 3.2.1.1.1 Mode 1 (within State 1) Name
      - » 3.2.1.1.1.1 Performance Capability (1)
      - » 3.2.1.1.1.n Performance Capability (n)
    - 3.2.1.1.2 Mode 2 (within State 1) Name
      - » 3.2.1.1.2.1 Performance Capability (1)
    - 3.2.1.1.2.n Capability (n)
      - » 3.2.1.1.n Mode n (within State 1) Name
      - » 3.2.1.1.n.1 Performance Capability (1)
    - 3.2.1.1.n.n Performance Capability (n)
  - 3.2.1.2 State 2 Name
    - 3.2.1.2.1 Mode 1 (within State 2) Name
      - » 3.2.1.2.1.1 Performance Capability (1)
        - 3.2.1.2.1.n Performance Capability (n)"

SYSTEM State ?
- STORAGE
- RELOCATION
- SET-UP / TEAR-DOWN
- OPERATION
- DISPOSAL

DYNAMIC State?
- Loading
- Taxiing TO / FROM
- Taking OFF
- Ascending
- Cruising
- Descending
- Landing
- Unloading

•Source: *SMC System Engineering Primer and Handbook, Appendix C10–States & Modes, Appendix C-10, p. 220.*

Specifying Modes & States in Specifications

- **New Development - AVOID development of a MODES & STATES-centric specification UNLESS:**
  - There is a compelling need
  - You thoroughly understand:
    - What you are doing
    - The problem or issue the user is trying to solve.

- **IF you decide to develop a MODES & STATES-centric specification, you MUST document ALL of the performance requirements associated with a specific STATE & MODE.**
  - DO NOT list only a few requirements relevant to the topic.
  - Remember – IF a MODE or STATE is required, System Integration and Test will need to see ALL of the requirements documented in the specification to serve as the basis for compliance verification.

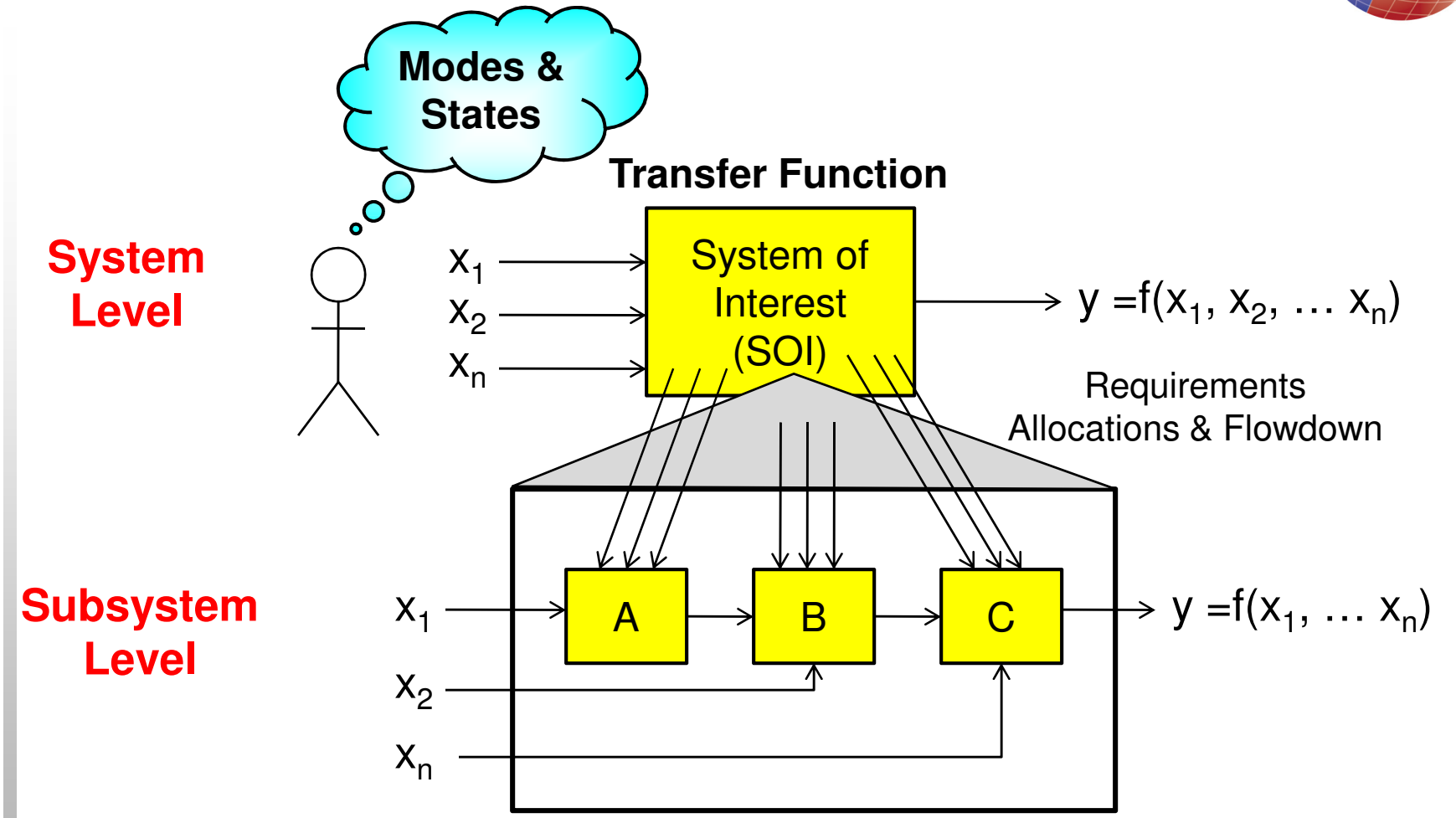
- **Remember – IF you specify MODES & STATES in a specification, you MAY have <u>inadvertently</u> limited the scope of available candidate architectural design options including what might have been the optimal architecture.**

States & Modes in Specs Guidance

- **A source for guidance in specifying Modes & States requirements in specifications is:**
  - *SMC System Engineering Primer and Handbook, Appendix C10–States & Modes, Appendix C-10, p. 219 – 221.*

Issue #4
Should Specification Modes & States Requirements be Flowed Down to Lower Level Components?

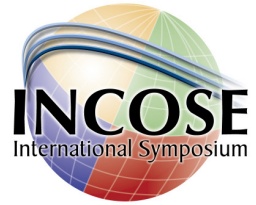
Flowing Down Spec M & S to Lower Levels???



Recommendation: Flow only "leaf level" requirements down to lower level entities

Summary

Executive Summary (1 of 5)



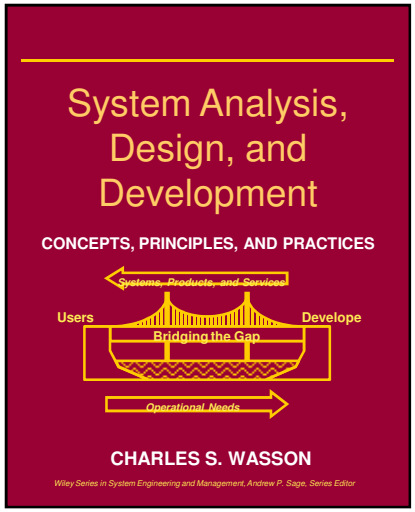
- **Issue #1**
  - What is the difference between a mode and a state?
- **Issue #2**
  - Do Modes contain States or do States contain Modes?
- **Issue #3**
  - Should specifications explicitly state M & S requirements?
- **Issue #4**
  - Should specification M & S requirements be flowed down?

Concluding Remarks

- **System Engineers must exhibit leadership skills in:**
  - Facilitating Project–User consensus definitions for MODES & STATES and their entity relationships (ERs):

- **Ensuring those definitions are:**
  - Well-communicated and understood by project personnel and functional management.
  - Necessary and sufficient for system development to minimize inefficient and ineffective usage of limited project resources.
  - Unambiguous and not subject to misinterpretation.
  - Documented via a project glossary that has been approved, baselined, and under formal configuration change control.
  - Consistently applied throughout all project documentation.

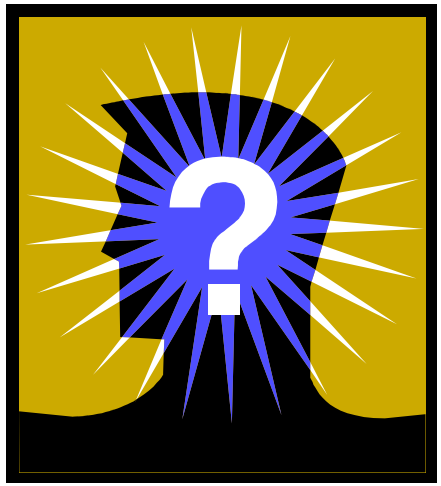
Additional Reading



John Wiley & Sons, Inc. (New York)

- Wasson, Charles S. *System Analysis Design and Development: Concepts, Principles, and Practices*, Chapter 19 - System Phases, Modes, & States of Operation, John Wiley & Sons, Inc. (New York)
- Wasson, Charles S., *System Phases, Modes, & States: Solutions to Controversial Issues*, INCOSE IS2011, Denver, CO, 2011
- Edwards, Michael Thomas *A Practical Approach to State and Mode Definitions for the Specification and Design of Complex Systems*, 2003 System Engineering Test & Evaluation Conference (SETE) Rydges Capital Hill, Canberra, Australia, 27-29 October 2003, dated 17 September 2003.
- Source: *Unmanned Systems Safety Guide for DoD Acquisition*, First Edition, 27 June 2007.
- SMC *System Engineering Primer and Handbook*, *Appendix C10–States & Modes,* Appendix C-10, p. 220.

Questions and Answers



Charles S. Wasson
Wasson Strategics, LLC
www.wassonstrategics.com
wslse@cpws.net