A STRUCTURED APPROACH TO SCENARIO GENERATION FOR THE DESIGN OF A CREW EXPERT TOOL

Iya Whiteley - SEA iw@sea.co.uk
Olga Bogatyreva - Univ. of Bath
Chris Johnson - Univ. of Glasgow
Mikael Wolff - ESA
Martin Townend - SEA

Systems Engineering & Assessment Ltd in the framework of European Space Agency contract 21584/08/NL/HE

esa

S·E·A

EXPERT TOOL TO SUPPORT CREW AUTONOMOUS OPERATIONS IN COMPLEX HUMAN SPACECRAFT

- **WHO**
  - ⇨ SEA contracted by the European Space Agency (ESA)
- **WHY:**
  - ⇨ To investigate how support crew in problem-solving & a troubleshooting process
  - ⇨ To enabling ESA to support autonomous operation of the crew on long-duration missions

iya.whiteley@sea.co.uk

Stages of the Study

- **Review tools & techniques to support crew problem solving & troubleshooting activities**
  - ⇨ To define a range of problem solving crew functions & crew autonomous operations; confirm through user interviews
  - ⇨ To review tool & techniques to support them
- **Define iterative design & assessment for a Crew Expert Tool (CET)**
  - ⇨ To devise a matrix for definition of scenarios & confirm through user interviews
  - ⇨ To defining iterative design & assessment process
- **Establish requirements baseline & technical specification for Crew Expert Tool**
  - ⇨ To define preliminary functional requirements for interactive CET
  - ⇨ To define preliminary user interface requirements for interactive CET
- **Design & assessment of a CET proof-of-concept demonstrator**
  - ⇨ To design & evaluate CET proof-of-concept demonstrator
  - ⇨ To provide recommendations for development, maintenance & evolution process of CET

esa

S·E·A

iya.whiteley@sea.co.uk

Background to Structured Approach to Scenario Generation

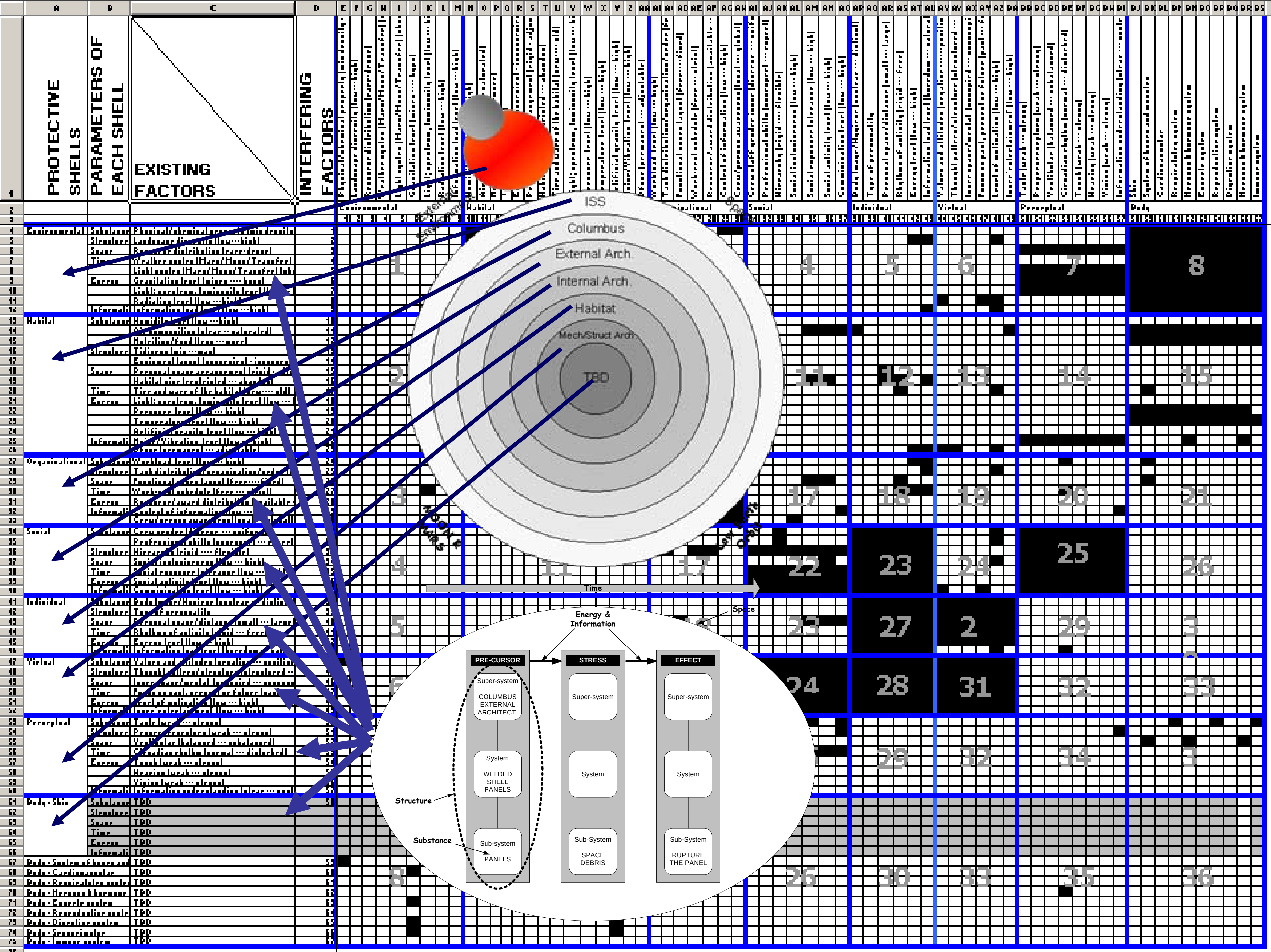
- **Originally developed for an ESA Study to define a range of Psychological & Social scenarios for Moon & Mars missions**
- **Adapted from TRIZ & Bio-TRIZ techniques**
  - ⇨ TRIZ – Theory of Inventive Problem Solving (Altshuller, 1946) - Engineering
  - ⇨ Bio-TRIZ (Bogatyreva & Bogatyrev, 2006) – Biology & Ecology
- **TRIZ has varieties of tools used to clarify the nature of the problem & methods of arriving at a number of solutions using available resources**

iya.whiteley@sea.co.uk

Structured Approach to Scenario Generation

- **Retrieves & methodically unites specialists experience & expertise in specific systems**
- **Accounts for lessons learned from accident & incidents**
- **Investigates mitigating actions taken by crews in similar existing systems & situations**
- **Consists of:**
  - ⇨ Scenario Generating Matrix (SG-Matrix)
  - ⇨ Definition of Environment & Protective Shells
  - ⇨ Context-defining dimensions

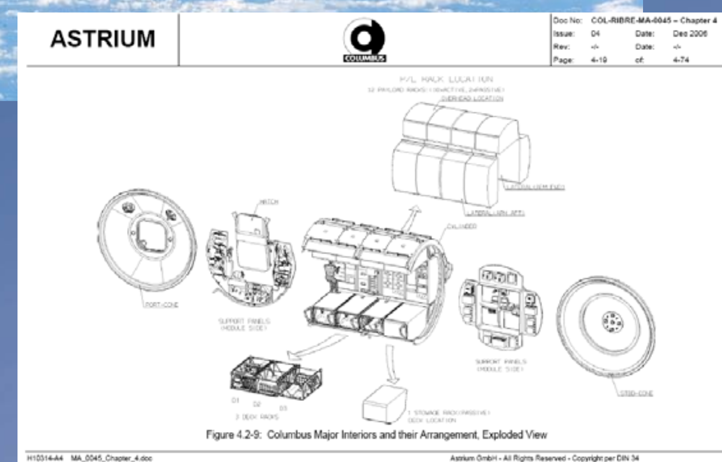
iya.whiteley@sea.co.uk



PROTECTIVE SHELLS
PARAMETERS OF EACH SHELL
EXISTING FACTORS
INTERFERING FACTORS
ISS
Columbus
External Arch.
Internal Arch.
Habitat
Mech/Struct Arch
TBD
Time
Energy & Information
Space
PRE-CURSOR
STRESS
EFFECT
Super-system
COLUMBUS EXTERNAL ARCHITECT.
System
WELDED SHELL PANELS
Sub-system
PANELS
Super-system
System
Sub-System
SPACE DEBRIS
Super-system
System
Sub-System
RUPTURE THE PANEL
Structure
Substance

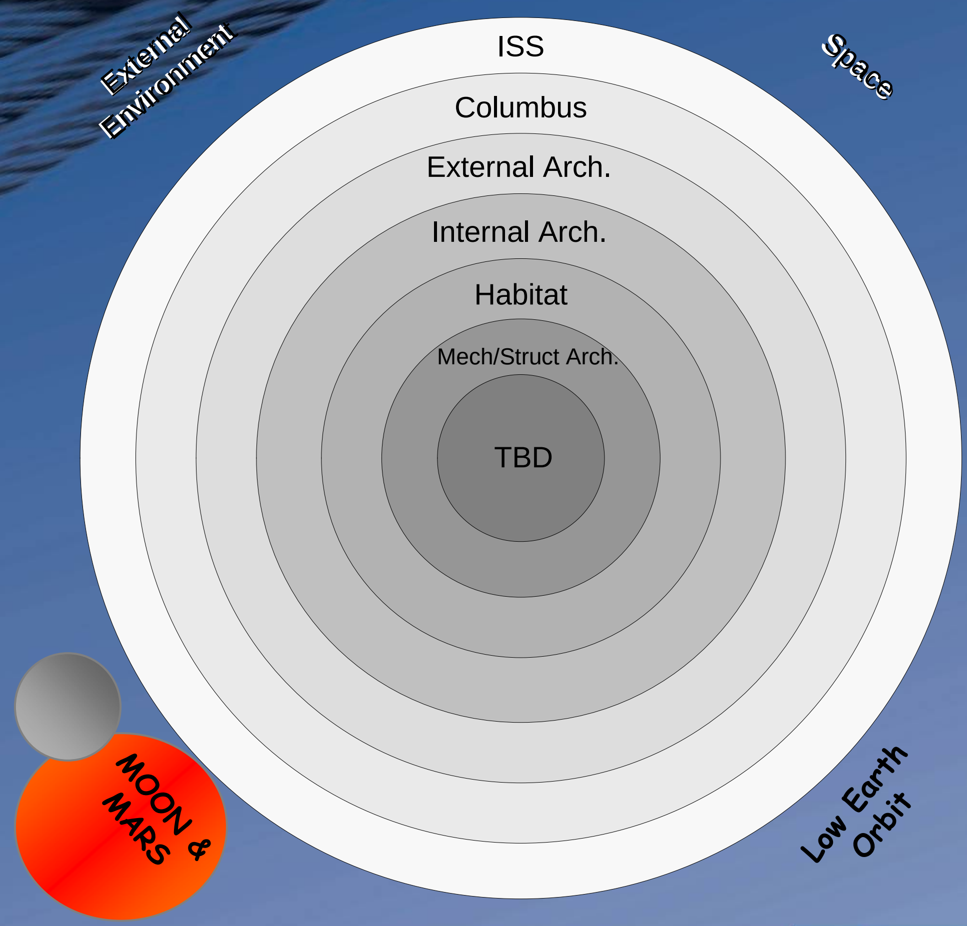
Mission Environments & Protective Shells

- **Mission Environments**
  - ⇨ Low Earth Orbit
  - ⇨ Open Space
  - ⇨ Moon surface
  - ⇨ Mars surface
- **Protective Shells**
  - ⇨ International Space Station
  - ⇨ ISS Modules, e.g. Columbus
  - ⇨ Columbus External Architecture
  - ⇨ Columbus Internal Architecture
  - ⇨ Basic Habitability & Outfitting for IVA & EVA
  - ⇨ Mechanical / Structural Architecture
  - ⇨ Environmental & Thermal Architecture



iya.whiteley@sea.co.uk

Mission Environments & Protective Shells



System Architecture / Shells	Shell Dimensions	Existing Contradicting Factors interfering / triggering	Physical/chemical property (min density -max density)	Landscape diversity (low --- high)	Resource distribution (rare --- dense)	Weather cycles (short --- long)	Light cycles (short --- long)	Gravitation level (micro ---- hypo)	Light; spectrum, luminosity level (low --- high)	Radiation level (low --- high)	Information load level (low---high)	...	Thermal protection properties	Radiation protection properties	Shielding protection properties	Welded shell panels	Cylindrical shells	Wear and tear	Pressure containment	Thermal conductivity	Feedback system	Detection system	...
Space environment	Substance	Physical/chemical property (min density - max density)																					
	Structure	Landscape diversity (low --- high)																					
	Space	Resource distribution (rare --- dense)																					
	Time	Weather cycles (short --- long)																					
		Light cycles (short --- long)																					
	Energy	Gravitation level (micro ---- hypo)																					
		Light; spectrum, luminosity level (low --- high)																					
		Radiation level (low --- high)																					
	Information	Information load level (low --- high)																					
ISS	Substance	...																					
	Structure	...																					
	Space	...																					
	Time	...																					
	Energy	...																					
	Information	...																					
Columbus Module	Substance	Thermal protection properties																					
		Radiation protection properties																					
		Shielding protection properties																					
	Structure	Welded shell panels																					
	Space	Cylindrical shells																					
	Time	Wear and tear																					
	Energy	Pressure containment																					
		Thermal conductivity																					
	Information	Feedback system																					
		Detection system																					
...		...																					

Wear and tear of the habitat

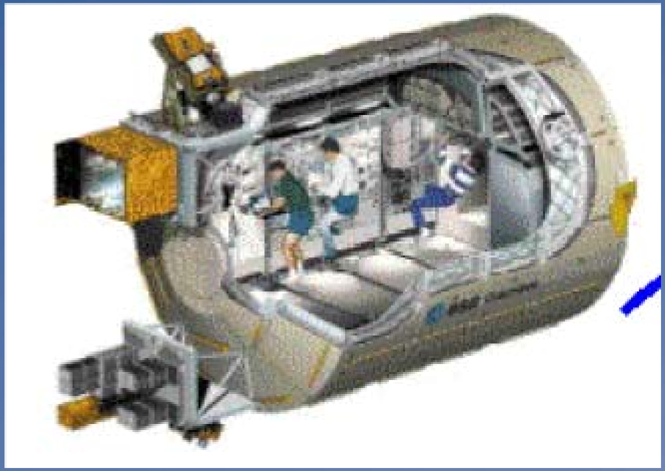
iya.whiteley@sea.co.uk

Mission Environments Elements

- **Environment**
  - ⇨ Physical/chemical property
  - ⇨ Landscape diversity
  - ⇨ Resource distribution
  - ⇨ Weather cycles
  - ⇨ Light cycles
  - ⇨ Gravitation level
  - ⇨ Light; spectrum, luminosity level
  - ⇨ Radiation level
  - ⇨ Information load level

Columbus Module Elements

- **Columbus Module**
  - ⇨ Thermal protection properties
  - ⇨ Radiation protection properties
  - ⇨ Shielding protection properties
  - ⇨ Welded shell panels
  - ⇨ Cylindrical shells
  - ⇨ Wear & tear
  - ⇨ Pressure containment
  - ⇨ Thermal conductivity
  - ⇨ Feedback system
  - ⇨ Detection system



iya.whiteley@sea.co.uk

Classification of Shell & Environment Elements into Dimensions

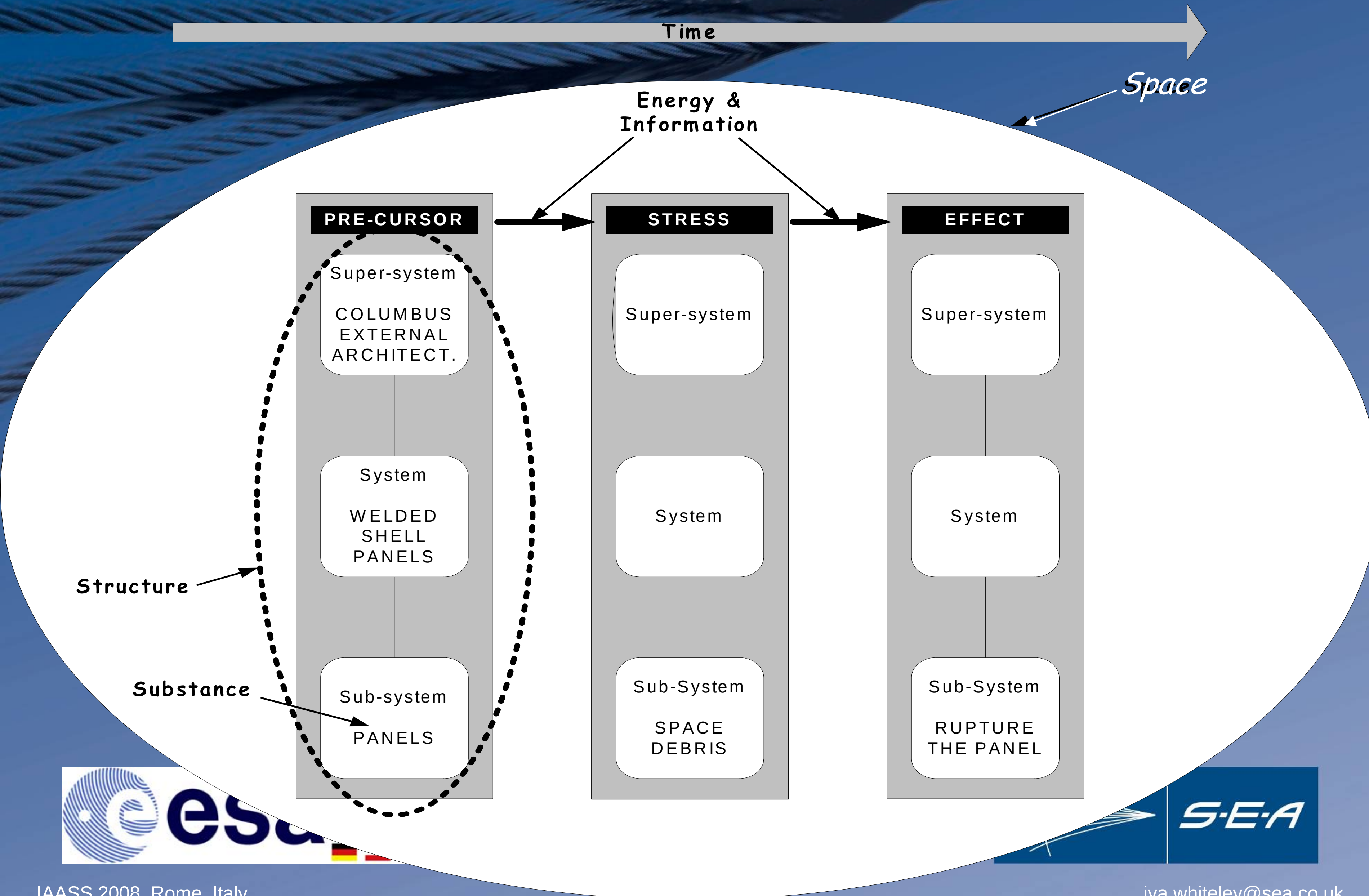
- **Substance**
  - ⇨ What is it made of?
- **Structure**
  - ⇨ How is it structured? What are its components?
- **Space**
  - ⇨ Where is it? What space does it occupy? How does it utilise space?
- **Time**
  - ⇨ When & how often & how does it change over time?
- **Energy**
  - ⇨ What energy does it use? How does energy affect the shell?
- **Information**
  - ⇨ How it works? How information is processed & controlled?

esa

S·E·A

iya.whiteley@sea.co.uk

Shell Dimensions to Model Situations



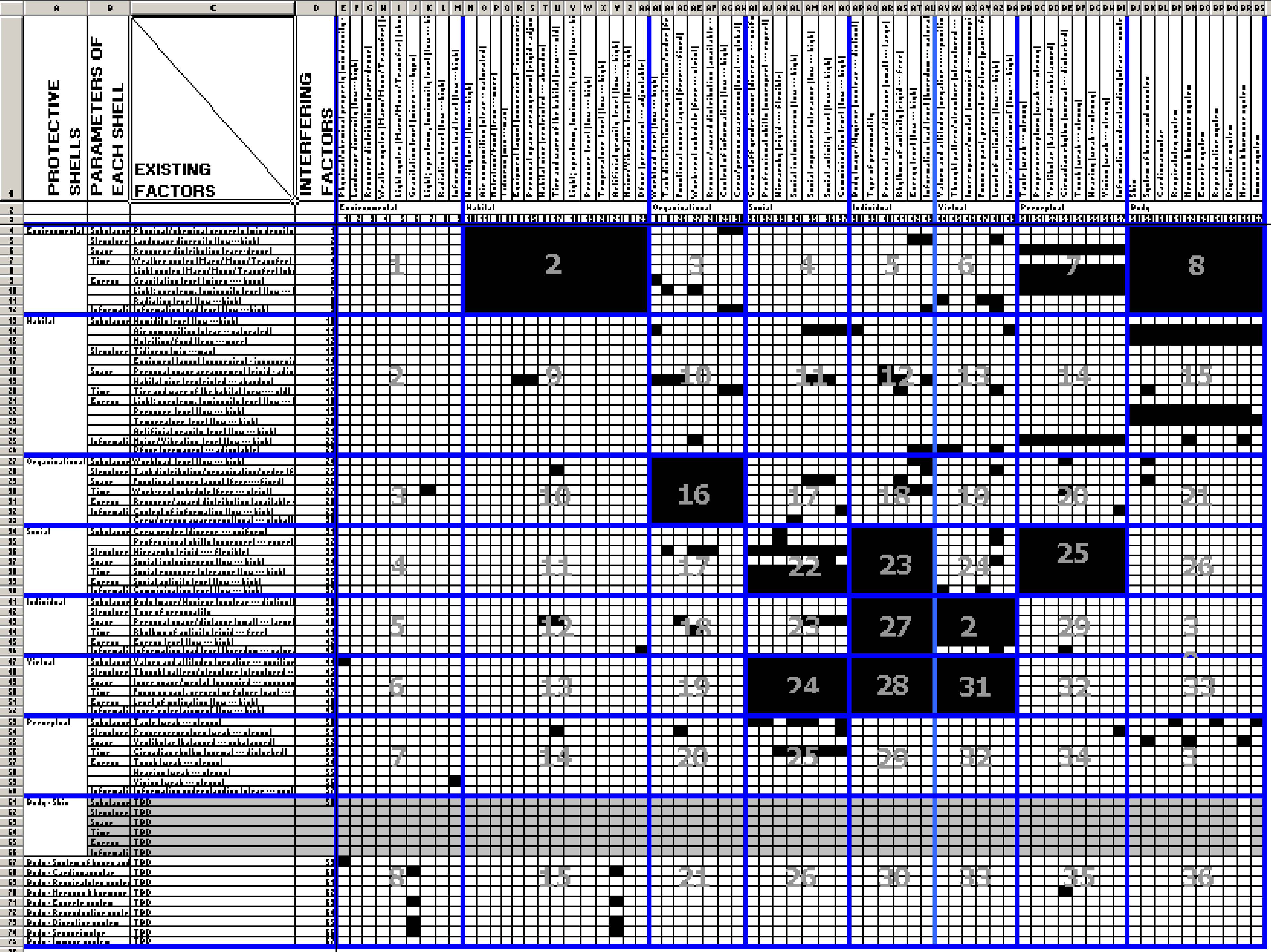
iya.whiteley@sea.co.uk

System Architecture / Shells	Shell Dimensions	Existing Contradicting Factors interfering / triggering	Physical/chemical property (min density -max density)	Landscape diversity (low --- high)	Resource distribution (rare --- dense)	Weather cycles (short --- long)	Light cycles (short --- long)	Gravitation level (micro ---- hypo)	Light; spectrum, luminosity level (low --- high)	Radiation level (low --- high)	Information load level (low---high)	...	Thermal protection properties	Radiation protection properties	Shielding protection properties	Welded shell panels	Cylindrical shells	Wear and tear	Pressure containment	Thermal conductivity	Feedback system	Detection system	...
Space environment	Substance	Physical/chemical property (min density - max density)																					
	Structure	Landscape diversity (low --- high)																					
	Space	Resource distribution (rare --- dense)																					
	Time	Weather cycles (short --- long)																					
		Light cycles (short --- long)																					
	Energy	Gravitation level (micro ---- hypo)																					
		Light; spectrum, luminosity level (low --- high)																					
		Radiation level (low --- high)																					
	Information	Information load level (low --- high)																					
ISS	Substance	...																					
	Structure	...																					
	Space	...																					
	Time	...																					
	Energy	...																					
	Information	...																					
Columbus Module	Substance	Thermal protection properties																					
		Radiation protection properties																					
		Shielding protection properties																					
	Structure	Welded shell panels																					
	Space	Cylindrical shells																					
	Time	Wear and tear																					
	Energy	Pressure containment																					
		Thermal conductivity																					
	Information	Feedback system																					
		Detection system																					
...		...																					

iya.whiteley@sea.co.uk

System Architecture / Shells	Shell Dimensions	Existing Contradicting Factors interfering / triggering	Physical/chemical property (min density -max density)	Landscape diversity (low --- high)	Resource distribution (rare --- dense)	Weather cycles (short --- long)	Light cycles (short --- long)	Gravitation level (micro ---- hypo)	Light; spectrum, luminosity level (low --- high)	Radiation level (low --- high)	Information load level (low---high)	...	Thermal protection properties	Radiation protection properties	Shielding protection properties	Welded shell panels	Cylindrical shells	Wear and tear	Pressure containment	Thermal conductivity	Feedback system	Detection system	...
Space environment	Substance	Physical/chemical property (min density - max density)																					
	Structure	Landscape diversity (low --- high)																					
	Space	Resource distribution (rare --- dense)																					
	Time	Weather cycles (short --- long)																					
		Light cycles (short --- long)																					
	Energy	Gravitation level (micro ---- hypo)																					
		Light; spectrum, luminosity level (low --- high)																					
		Radiation level (low --- high)																					
	Information	Information load level (low --- high)																					
ISS	Substance	...																					
	Structure	...																					
	Space	...																					
	Time	...																					
	Energy	...																					
	Information	...																					
Columbus Module	Substance	Thermal protection properties																					
		Radiation protection properties																					
		Shielding protection properties																					
	Structure	Welded shell panels																					
	Space	Cylindrical shells																					
	Time	Wear and tear																					
	Energy	Pressure containment																					
		Thermal conductivity																					
	Information	Feedback system																					
		Detection system																					
...		...																					

iya.whiteley@sea.co.uk


PROTECTIVE SHELLS
PARAMETERS OF EACH SHELL
EXISTING FACTORS
INTERFERING FACTORS

Populating Scenario Generating Matrix (SG-Matrix)

- **Using existing malfunction procedures analysis**
  - ⇨ define additional factors & generate more accurate case studies
- **Using accident & incident analysis**
  - ⇨ define additional factors & refine case studies
- **Using safety & risk analysis**
  - ⇨ prioritise the categories of scenarios, for example in terms of safety or regarding their level of importance in design

iya.whiteley@sea.co.uk

SG-Matrix

- **Provides systematic approach**
  - ⇨ to identify potential situations the crew will face
- **Helps**
  - ⇨ to define the degree of severity of potential situation & identify the component or element that can be varied to avoid the developing situation
- **Allows**
  - ⇨ traceability of factors in sufficient detail, to be addressed in design of future techniques & technology for psychological support

iya.whiteley@sea.co.uk

In Summary:
Structured Approach to Scenario Generation

- **Provides a framework for classifying & developing scenarios systematically**
- **Helps teams of different experts to predict or forecast potential problem situations by introducing their own additional factors**
- **Helps to consider a range of safety-critical scenarios the crew may encounter on missions to the Moon & Mars**
  - ⇨ For design & assessment of tools & equipment
  - ⇨ For developing potential future mission profiles & training scenarios
- **This ESA study applies this matrix to inform the design of a Crew Expert Tool to address potential problem scenarios in long-duration space missions**

iya.whiteley@sea.co.uk

esa

S·E·A

iya.whiteley@sea.co.uk