Simulation Based Operational Analysis of Future Space Transportation Systems

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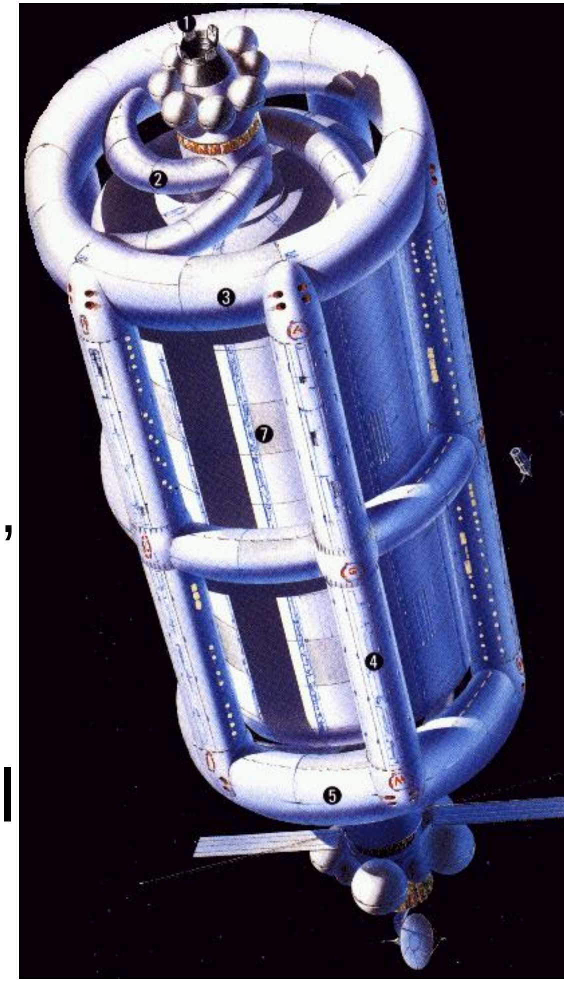
Did you know?

- Time between landing and launch for an orbiter?
- Cost to process (landing to launch)?
- Number of parts to be inspected, replaced?
- Person hours to process?
- Estimated cost per pound to orbit?

Answers: (1) ~140 calendar days, (2) over $300M each, if 8 flights per year, including fixed and variable costs, (3) Six Million parts, over 100 changed out in an orbiter between each flight, (4) 140,000 direct technician type man-hours to process each flight each orbiter, up to 500,000 man-hours with support personnel and ET and SRB, (5) about $6000/lb this year for operations, not including up-front and recurring investments.

The Future



http://www.spacefuture.com/archive/orbital_sports_stadium.shtml

- Space Tourism
  - A two hour cruise into 0 gravity,
  - A week at the Space Hilton,
  - A month at the moon?
- Ultra-fast Travel/Package Del
  - NY-Tokyo in two hours?
- Space Sports
- Manufacturing and Healthcare in 0 Gravity

Presentation Outline

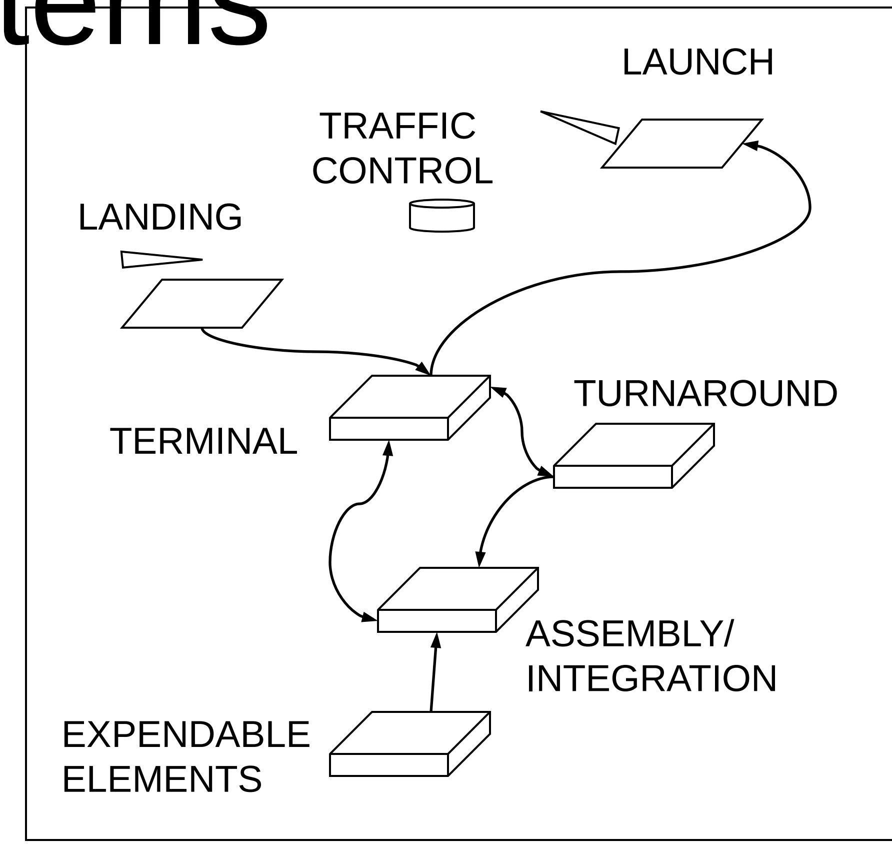
- Introduction and Research Objectives
- Space Transportation Systems
- Operations Cost Modeling
- KSBOM
- Prototype
- Conclusions and Future Directions

Introduction and Research Objectives

- Cost to access space must be reduced by several orders of magnitudes
- Vehicle designers need better understanding about operations
- Need better decision and assessment tools at early stages of design process
- O1: Develop an alternative methodology to the knowledge based utility functions of previous approaches.
- O2: Demonstrate the use of simulation as tool to evaluate future systems and “train” system designers

Space Transportation Systems

- Similar in “principle” to air transportation
  - Vehicles, Spaceports, Flight Control
- Higher Complexity of Vehicles – space is a “’difficult” environment



Operations Modeling

- The Generalized Problem
  - Given a LV architecture,
  - Estimate/Predict the single vehicle cost and operations characteristics
    - Per Flight Costs, Fixed Costs
    - Ground Cycle Time - Flight rate capability
  - Predict the LCC for the transportation system given demand forecasts scenarios (fleet of vehicles):
    - 30 + Million Lbs./Year
    - <1/2 Million Lbs../Year

Operations Modeling

- Why is it a difficult problem?
  - LV's are very complex systems (Ryan and Townsend 1997)
  - LV Architectures/concepts are often based on new and immature technologies where operations experts and designers have limited operations knowledge/data
  - Data for existing system is not always useful/complete
  - At the architectural/concept level a limited set of design characteristics have been set, not always focused towards operations.

Knowledge/Simulation Based Operational Analysis

- Based on ABC analysis and the estimation of activities, costs, and flows given a)design and b)knowledge
- Related to the Approach used by Christenson and Komar (1998) to model/ analyze reusable rocket engine operability
- ABC has been used in Manufacturing, Logistics,…
  - Costs assigned to a product based on the required production activities.
  - Activities have an associated activity time (duration) and resource requirements.
  - Activities have an associated cost rate that can be based on the type of activity, i.e.Labor intensive,Machine/equipment intensive, Technical support intensive

Knowledge/Simulation Based Operational Analysis

- Vehicle is defined by two variables
  - d_i = design option
  - q_i = quantity of an operational driver

$d_{tps\text{-}ct}$ = Ceramic tiles
$q_{tps\text{-}ct}$ = Surface area

$d_{tps\text{-}ct} = 1$
$q_{tps\text{-}ct} = 650$

$d_{tps\text{-}ct} = 0$
$q_{tps\text{-}ct} = 0$

Knowledge/Simulation Based Operational Analysis

- Activity Set and Characterization
  - *A* Spaceport Activities
  - s_a = activity option
  - p_a = processing time characterization for activity *a*
  - c_a = cost characterization for activity *a*
  - n_a = Expected need characterization for activity *a*

$s_{tps\text{-}insp}$ = 1
$p_{tps\text{-}insp}$ = U(1,3)hr * $q_{tps\text{-}ct}$
$c_{tps\text{-}insp}$ = $p_{tps\text{-}insp}$ * $100
$n_{tps\text{-}insp}$ = 100%

Knowledge/Simulation Based Operational Analysis

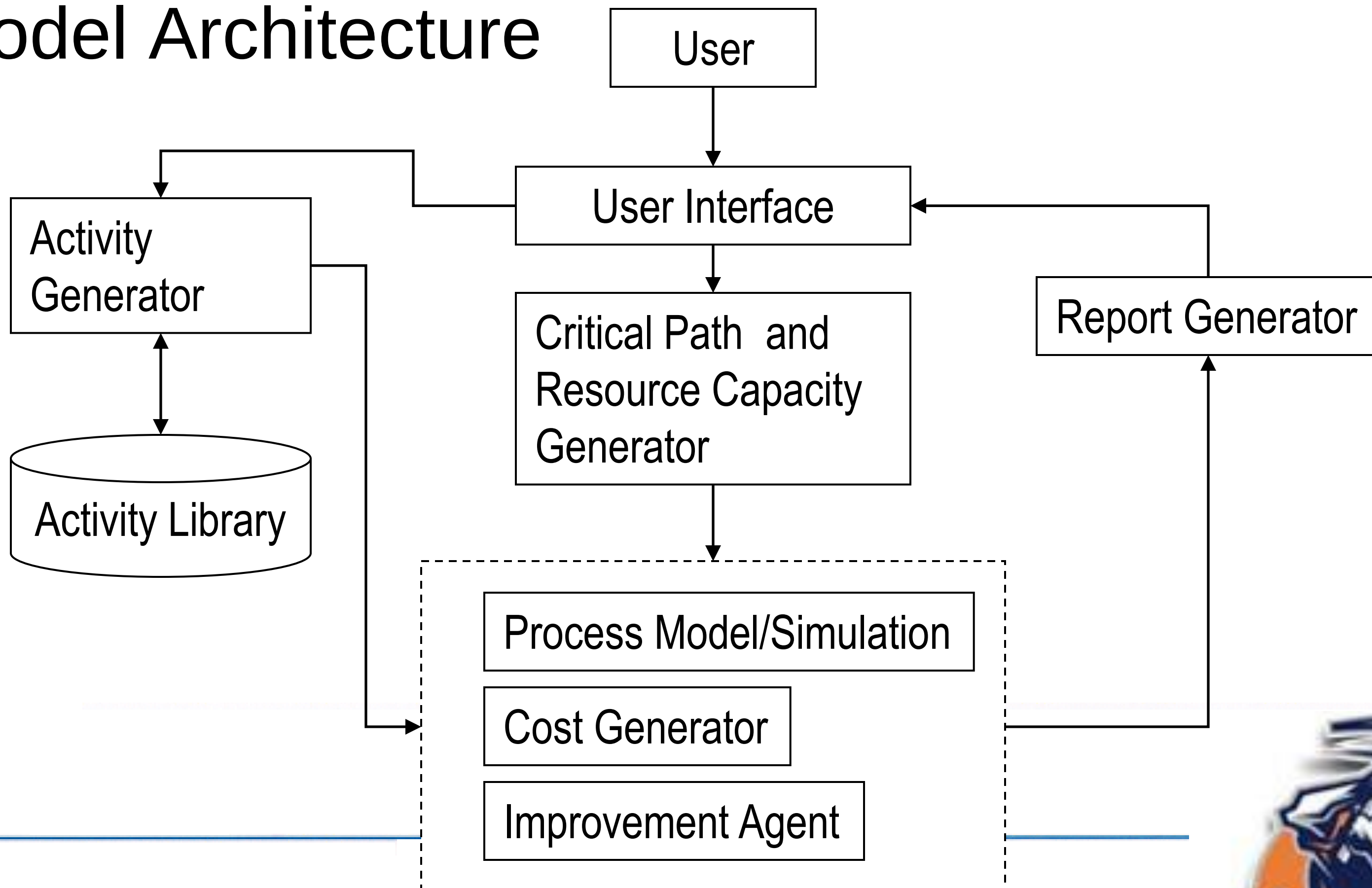
- Process Modeling
  - Spaceport is a “preset” network. Several networks may be defined to account for “technologies or spaceport approaches”
  - *R* resources with a set capacity per resource
  - Each resource has an assigned set of activities
  - To estimate resource requirements, a “lower bound” resource estimate is made based on the expected use of each resource with no time conflicts.

Knowledge/Simulation Based Operational Analysis

- The objective of the operational analysis is to estimate:
    - Flight rate / Ground Cycle time
    - Variable and fixed costs
    - $/Lb to Orbit
    - System complexity, reliability, operability measures (how "easy" is this system to operate/maintain)
    - Process requirements
    - Pareto Analysis of costs, times
    - Teach designers the effect of their choices

Knowledge/Simulation Based Operational Analysis

- Model Architecture

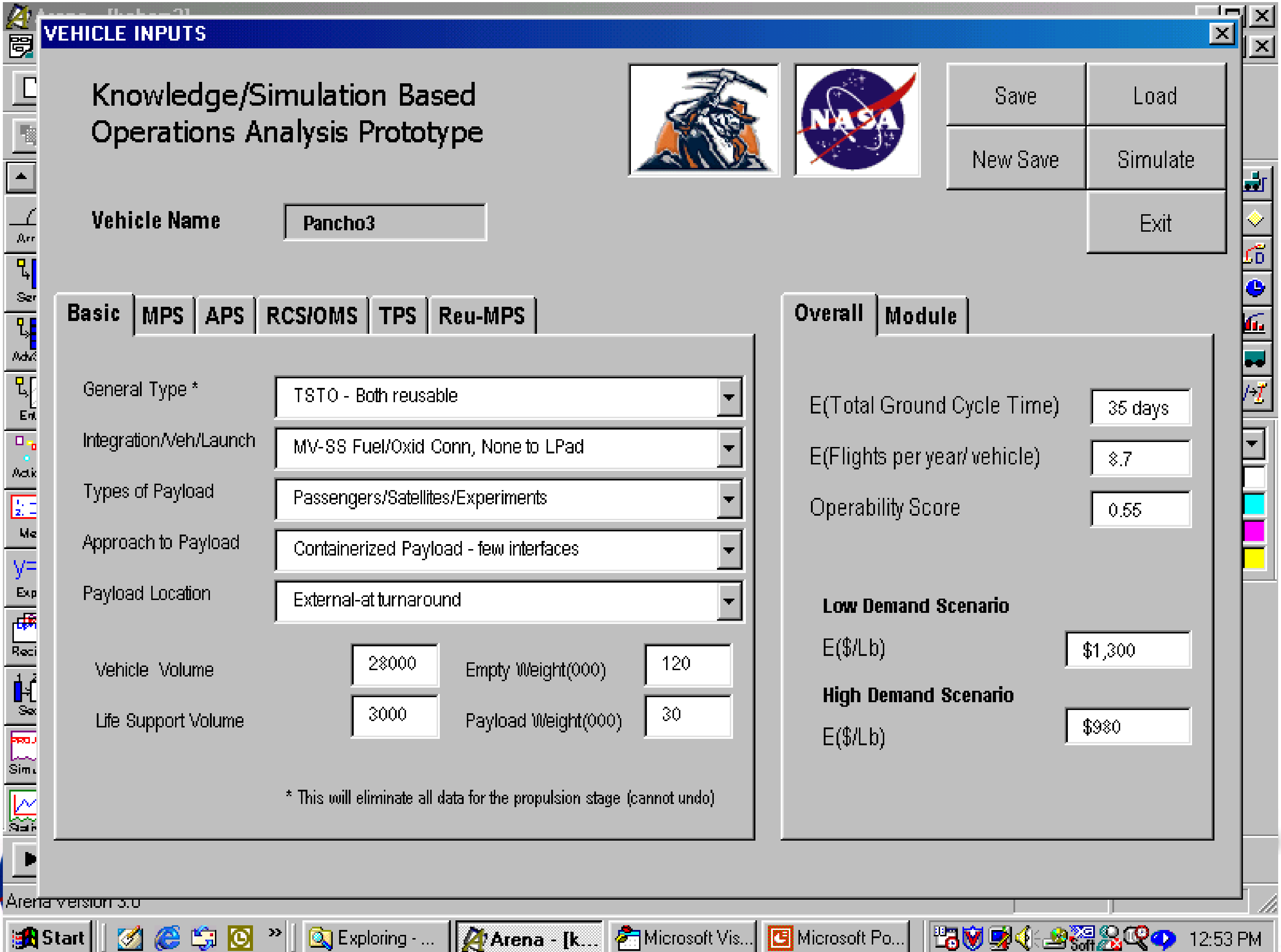


Knowledge/Simulation Based Operational Analysis

- Knowledge Requirements
  - Knowledge of existing processes
  - Estimates of effect of new technologies/processes
  - Testbeds/ NASA technology roadmap
  - Private space businesses experiences
  - Experience based “guessing”

Prototype

- Visual Basic and ARENA Simulation Software
  - VB functions as User Interface, Knowledge Engine, Activity Generator, …, and feeds the process model/activity characteristics to the Simulation model.
  - Still at development stage
  - No knowledge engine
  - One process model (one or two stage RLV)
  - Measures are based on “made up” knowledge equations
  - Additional outputs needed (Pareto of costs and time drivers for example)


VEHICLE INPUTS
Knowledge/Simulation Based
Operations Analysis Prototype
NASA
Save
Load
New Save
Simulate
Exit
Vehicle Name
Pancho3
Basic
MPS
APS
RCS/OMS
TPS
Reu-MPS
General Type *
TSTO - Both reusable
Integration/Veh/Launch
MV-SS Fuel/Oxid Conn, None to LPad
Types of Payload
Passengers/Satellites/Experiments
Approach to Payload
Containerized Payload - few interfaces
Payload Location
External-at turnaround
Vehicle Volume
28000
Empty Weight(000)
120
Life Support Volume
3000
Payload Weight(000)
30
* This will eliminate all data for the propulsion stage (cannot undo)
Overall
Module
E(Total Ground Cycle Time)
35 days
E(Flights per year/ vehicle)
8.7
Operability Score
0.55
Low Demand Scenario
E($/Lb)
$1,300
High Demand Scenario
E($/Lb)
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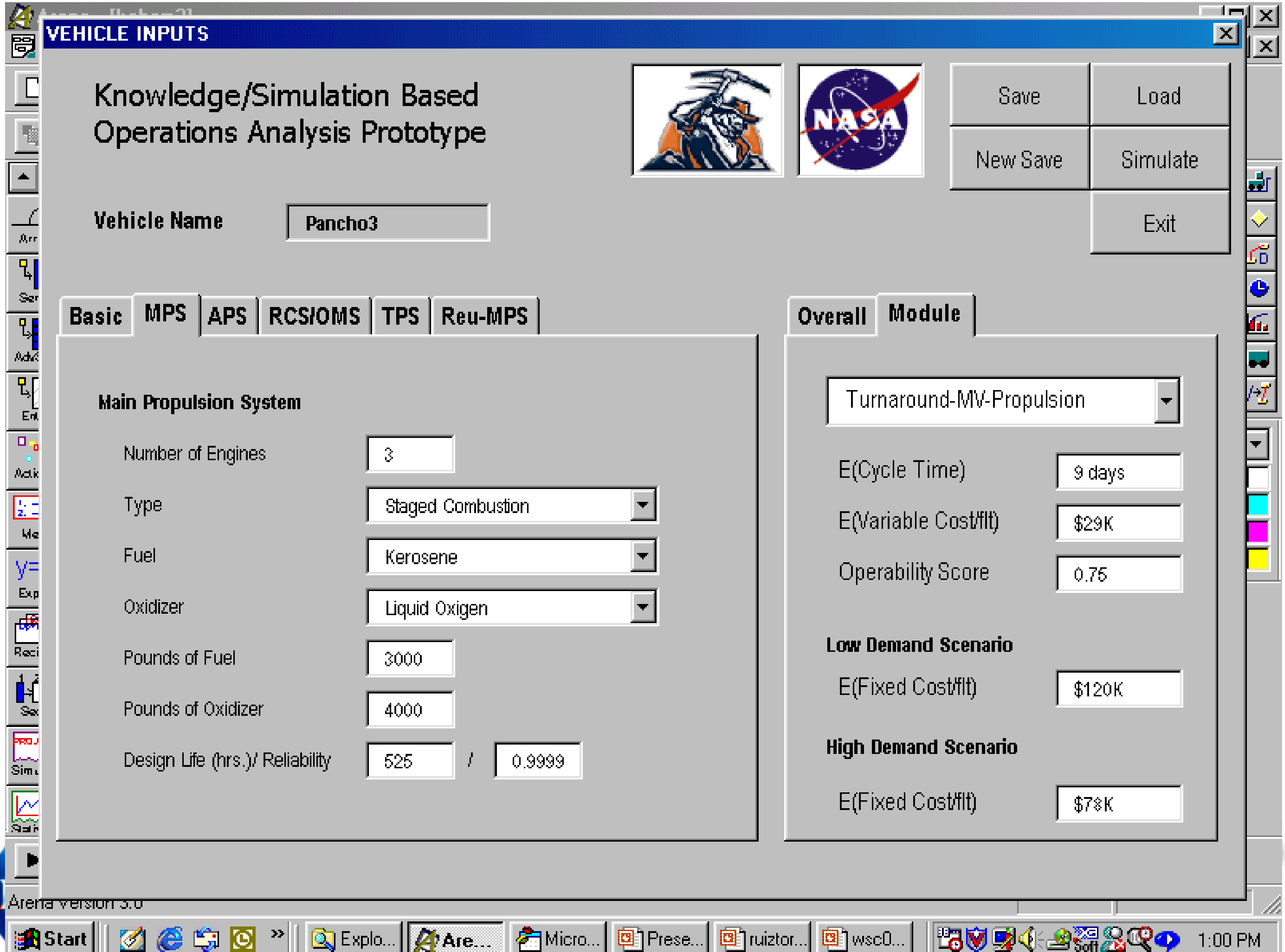
VEHICLE INPUTS
Knowledge/Simulation Based
Operations Analysis Prototype
Save
Load
New Save
Simulate
Exit
Vehicle Name
Pancho3
Basic
MPS
APS
RCS/OMS
TPS
Reu-MPS
Overall
Module
Main Propulsion System
Number of Engines
3
Type
Staged Combustion
Fuel
Kerosene
Oxidizer
Liquid Oxigen
Pounds of Fuel
3000
Pounds of Oxidizer
4000
Design Life (hrs.)/ Reliability
525
/
0.9999
Turnaround-MV-Propulsion
E(Cycle Time)
9 days
E(Variable Cost/flt)
$29K
Operability Score
0.75
Low Demand Scenario
E(Fixed Cost/flt)
$120K
High Demand Scenario
E(Fixed Cost/flt)
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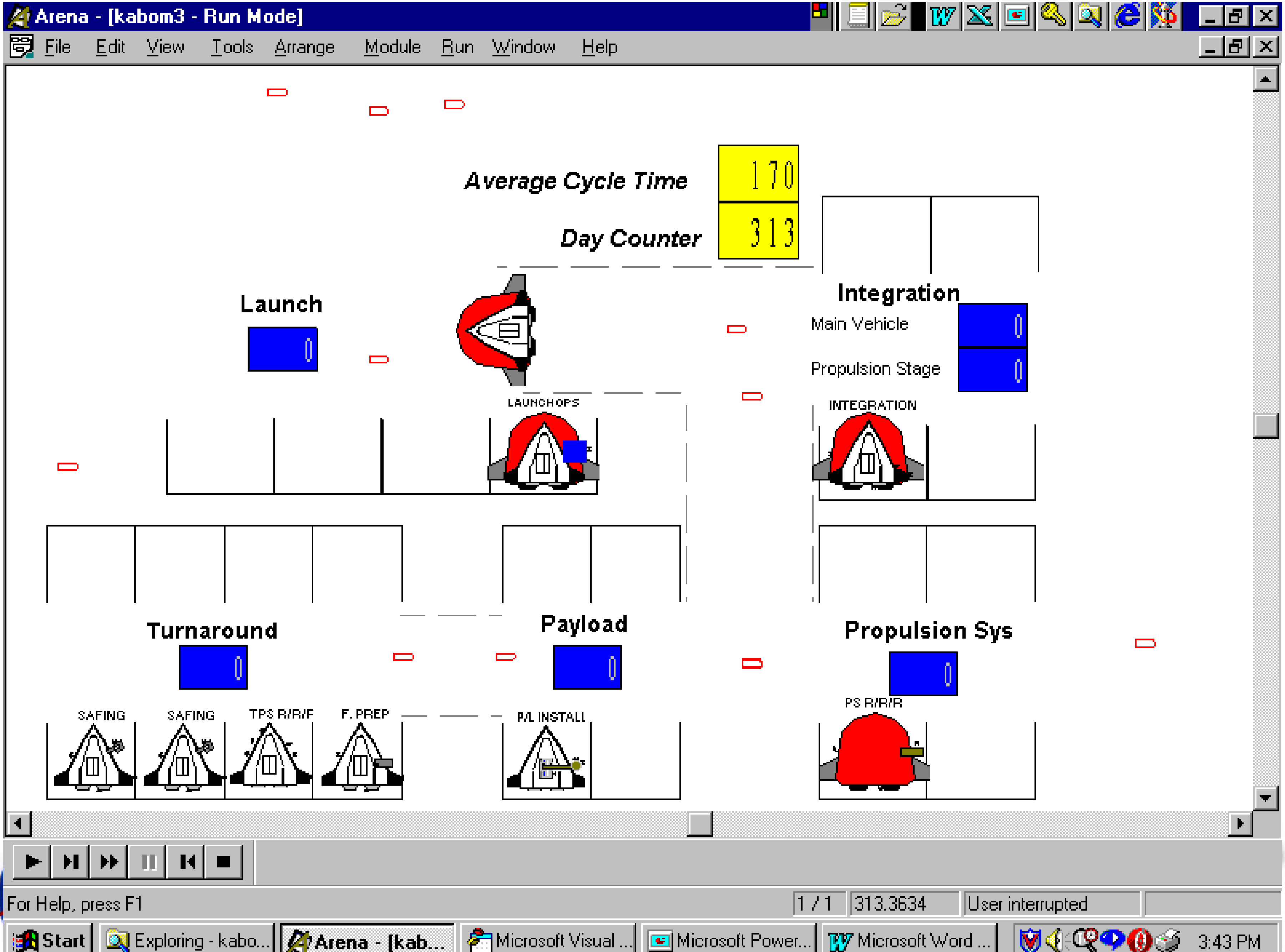
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File Edit View Tools Arrange Module Run Window Help
Average Cycle Time
170
Day Counter
313
Launch
0
Integration
Main Vehicle
0
Propulsion Stage
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LAUNCH OPS
INTEGRATION
Turnaround
0
Payload
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Propulsion Sys
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SAFING
SAFING
TPS R/R/F
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P/L INSTALL
PS R/R/R
For Help, press F1
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Arena - [kab...
Microsoft Visual ...
Microsoft Power...
Microsoft Word ...
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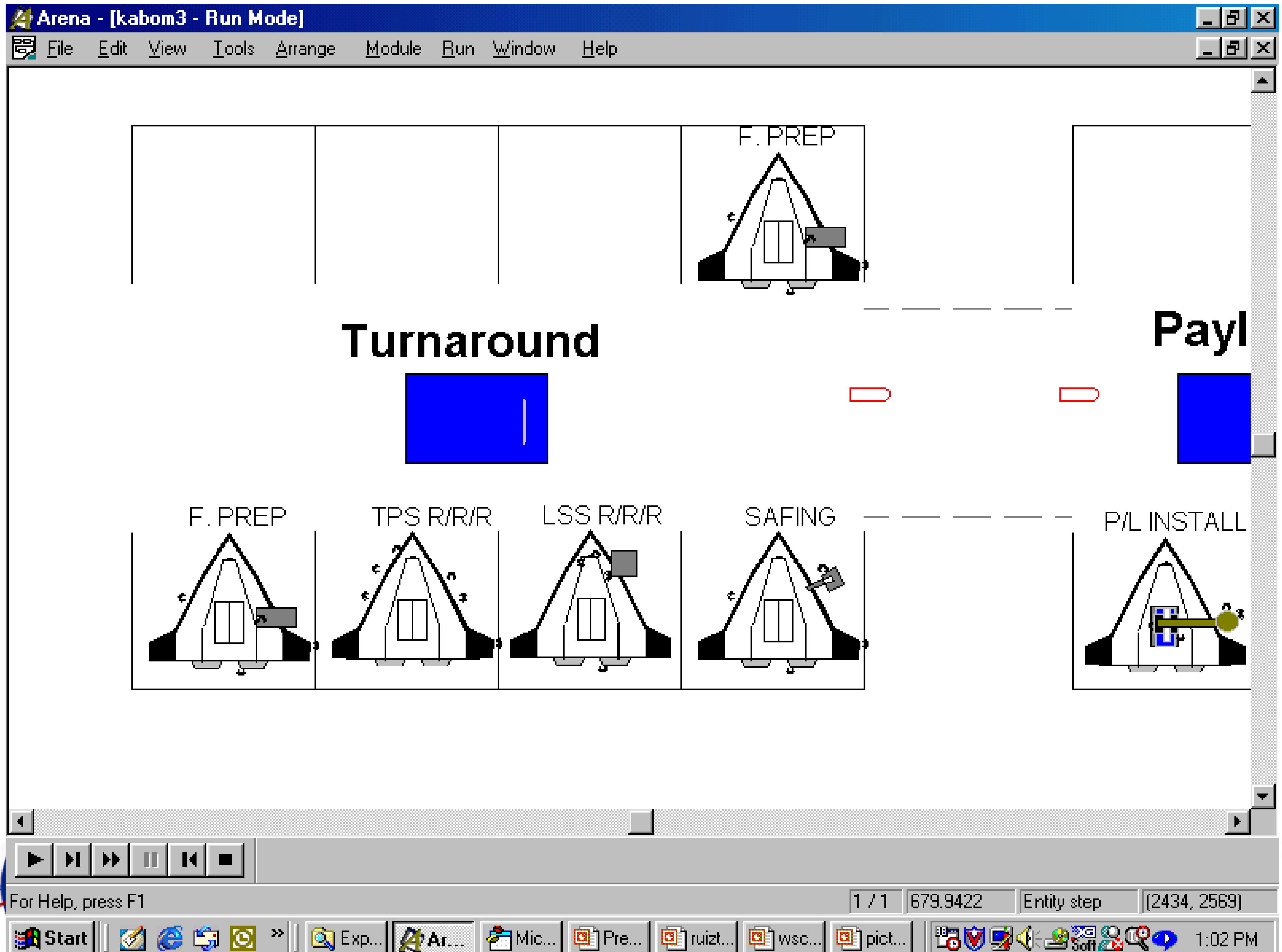
Arena - [kabom3 - Run Mode]
File Edit View Tools Arrange Module Run Window Help
F. PREP
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TPS R/R/R
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For Help, press F1
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Future Work

- Lots to do and in need of funding
- Moving from knowledge on existing processes to predicting activities and their characterization will be a challenging task
- From a 1956 book called the Real Book About Space Travel:

> *It does not seem likely that trips to other planets will become commonplace within the lifetime of any persons living today, but who knows? Scientific and technological developments are coming so fast that it seems impossible to keep up with all of them. Perhaps the science of space travel will progress more rapidly than anyone now guesses.*