Design to Cost

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Huntington Beach, CA, VESM109-001

ACADEMIC-INDUSTRY LIQUID ROCKET SYMPOSIUM **2023**

Mark Ventura CV

- BSME University of Pennsylvania
- MSE Purdue University, Rocket Propulsion
- Licensed California Professional Engineer
- World Expert Hydrogen Peroxide Propulsion
- Space Shuttle, X-34, UARS, Space Station, EELV, Mars Lander, Comsat, ABL, THEL, VG, VO, O&G, Cryport, New Space, solar, lots I can't talk about

- **COPV**
- Space Shuttle Main Propulsion Helium Sub-System Expert
- Helium tank thermo-fluid dynamic modeling simulation
- Helium tank transient thermodynamic modeling and simulation
- Design change from Kevlar/Titanium to GrEp/SS
- New Space pressurant tanks
- Chilled helium fast fill

- **Cost**
- 10 years conventional aerospace
  - Rockwell International, X-34 Stage 1 Propulsion Manager ~ $30M in ~ '94
- 25 years entrepreneurial
- Routinely compete FFP with large and small companies
- Large, small, conventional and unconventional business
- Mature and VC

- **Cryogenics**
- LO2, LH2, LN2, LNG, CH4, Neon, N2O*, CO2*
- Space Shuttle Main Propulsion
- Space Shuttle cryo payloads
- Space Station cryo supercritical tanks
- High energy density cryo mixed fuel/oxidizer blends
- Cryoport start-up
- Dry Ice makers, biotech
- New Space tank testing

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Factors that Create Cost Issues

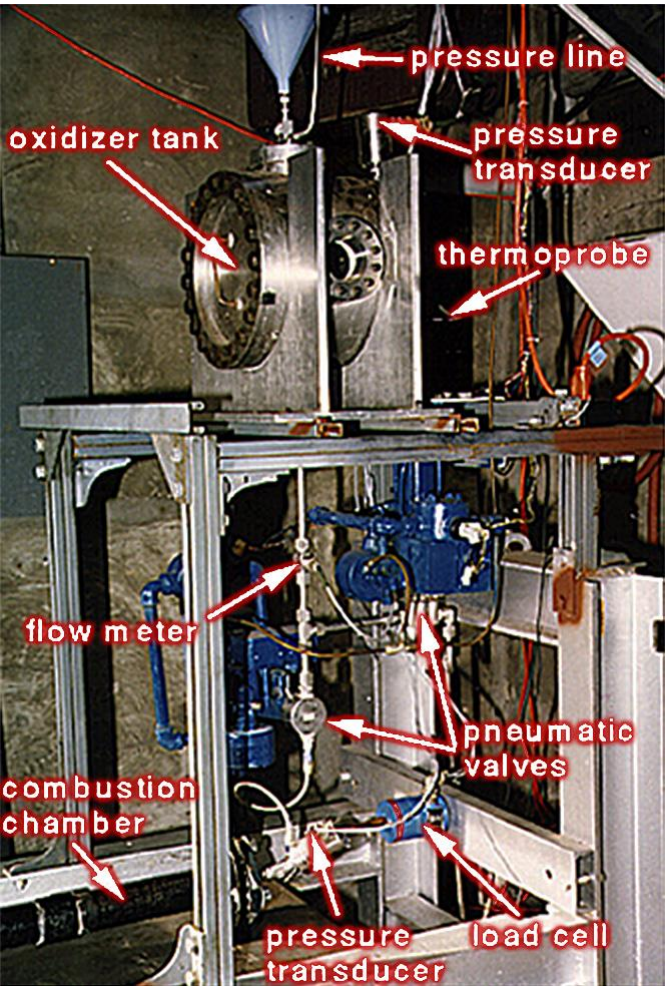
- Fundamental design decisions that incur larger than necessary cost
- Inefficient use of labor

- Solving technical problems with cost that have other lower or no-cost solutions
- Copying expensive practices
- Programmatic features that conflict with academic scale constraints

Expensive	Lower Cost
Industry best practices	KISS
Herd operations	Industrial eng.
Buy parts	Repair parts
COTS solenoid	Custom valves
valves	2-person max lift
Battleship test stands	

Can I Buy Everything at Target? Two Examples

Ventura MS 85% H2O2 Hybrid



Scrap combustion bomb
Trash Unistrut
Scrap I-beam, wind tunnel
Trash irrigation pipe
Odds and end fittings, eclectic
Unused valves, Purdue
Borrowed P-ducers
Scrap TC wire
Ice water TC junction

<u>Purchased parts</u>
2 Teflon o-rings for tank
Propellant
Passivation chemicals
Minor pipe fittings

<u>School OPEX – GN2</u>
<u>School CAPEX – Lab equip</u>
<u>Donation – Welder</u>
<u>5 heads, 1 semester</u>

Ventura RRS 85% H2O2 Hybrid

Blowdown pressurization
Fill valve – pipe plug
PVC structure
Solvent welded joints
“No machined parts”
Simple graphite nozzle
Simple pyro valve

Catalytic ignition
All materials fit inside small car
Hand tools, drill press
Commercial injector
One moving part
Duct tape
Hose clamp
C-clamps
Unistrut

Complexity Drives Cost

- If it does not exist it:
  - Has no material cost
  - Has no integration cost
  - Has no non-recurring/engineering cost
  - Cannot break
  - Has zero mass

- Every feature, component, and function adds cost
- Learn creativity in reducing complexity

Amateur or Professional

Complex	Simple
Regulated	Blowdown
Flight controls	Nothing
Crane ops	Manual lift
Cryogenic	Storable
Haz gas	None
Assy req’d	Pre-assembled
Pyrotechnics	None
Flight data	None or limited

Simple Looks Like a Hobby Solid – Use that as a goal

Design goal is Hobby Solid NRE, Rec, and Ops cost

Labor is a Finite Cost #1 Squandered Asset

- Labor is often very poorly utilized
- Large numbers of lookey-loos
- Labor is actually a finite resource, your team can only work so many hours per quarter/semester

14 persons
Maybe 1-2 working

- Getting people to work effectively is WORK (aka management)
  - Telling people to do something is not very effective
  - Training and showing people what to do is leadership
- Simplify program goals to fit what is doable

Tools and Tips

- Track labor costs, use a time clock and WBS
- LEARN by reconstructing actuals and compare
- Detailed tasks statements, not make it happen

Expensive Copycat Examples

- COTS cryogenic solenoid valves
- Pressure regulated pressurization
- Helium
- Trick custom propellant valves
- Trailer test skid

- Heavy weight run tanks
- Swage-lok style fittings
- COPV
- Buy everything, focus on cash as a program management tool

Lower Cost Solutions

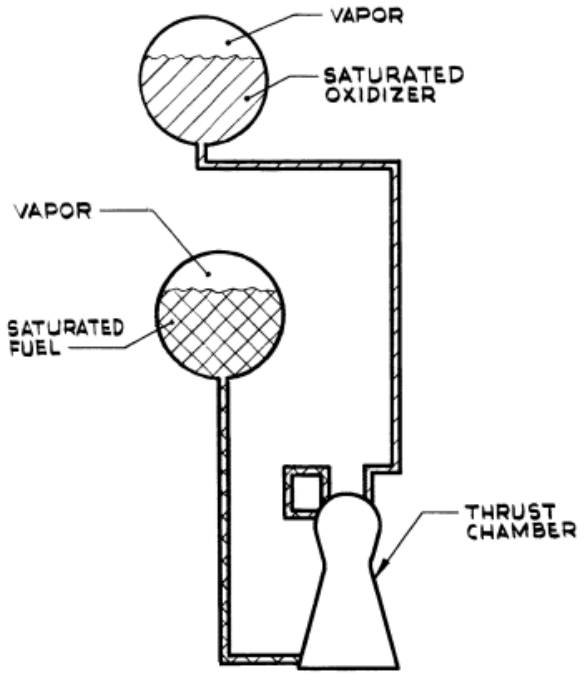
- Fix surplus regulator vs buy $1000 regulator
- Swagelok vs 37 degree flare fittings
- Large tanks vs “to size” or undersize tanks
  - Weight
  - Handling
  - Lifting and rigging
  - Pressurant gas
  - Higher cost fittings

- On-campus “junk”, find a scrounger
- Hoard materials
- Make friends, network, trade with other groups
- Scrap materials

Programmatic Cost Drivers

- Large Heavy “Mobile” Test Stand
  - Doubles materials, labor, NRE, fixes recurring costs
  - More opex: Labor, crane, forklift, trailer, truck, rigging
  - Doubles validation for flight system
- Pressure regulated
  - Eliminates pressurant tank, high pressure ops, F/D vlvs, relief/burst, fittings regulator(s), filters, bracketry and development
- Cryogenics
  - No time constraints
  - Parts easier to source, Less GSE
  - Less hazards and failure modes

80/20 Concept



Vapak Pressurization

NASA/GSFC, Study of Pressurization Systems for Liquid Propulsion Rocket Engine, Report 2335, 9/15/1962

Questions

- Is additive manufacturing lower cost than subtractive manufacturing?
- What is the average labor rate for an aerospace engineer in Southern California and Huntsville, Alabama?

- What are the metrics of Earned Value and what do they mean? How are they used?
- What is the legal difference between Exempt and Non-Exempt employees?
- Can you name an engineering organization that uses collective bargaining?

- Investment casting is over 5000 years old. Where is it used? What are the benefits? Is AM better?
- What are the Taguchi Method and the Design of Experiments?
- How much did my rocket engine test cost using:
  - Minimum wage
  - Low end fully wrapped labor rates
  - Typical industry labor rates?

Keep It Simple Stupid (KISS)

- Simple systems are harder to design
- Engineers tend towards complex
- Good RRS examples: Wherley, Claflin, McKinnon
  - ~ 1 person teams, ~ 2 years to design build, static fire and fly 1000 lbf LO2/fuel bi-props
  - Static fired flight hardware

"If it doesn't work, we'll drink the fuel."

Wherley LO2/alcohol rocket

- One (1) person can ship device in a sedan car
- Set-up and deploy in 2 days (~ 20 to 30 hrs)
- Limits Ground Support Equipment
- De facto limits Labor cost

Analog gauge
D2 tank
Surplus piece parts
Flight weight static fire
Copper lines field fab

Who Cares?

- 1 test per quarter/semester/year
- Typical Field Deployment ~ 800 hrs
- Typical Quarter/Semester ~ 4000 hrs (2 person years)
- Typical cash budget $10,000

- Value ~ 1-2 test per year

- Cost for 1-2 test per year
- Minimum wage $72,000
- Lowest likely industry labor value $210,000
- Likely industry cost > $400,000

What happens to the value if you double the number of tests?