New Heavy Launchers, a Cost Estimate Challenge

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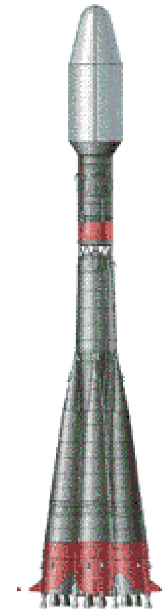
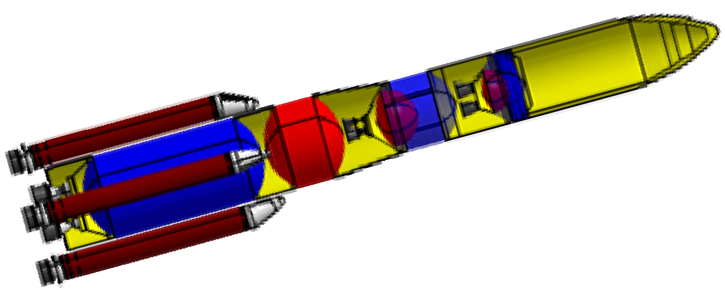
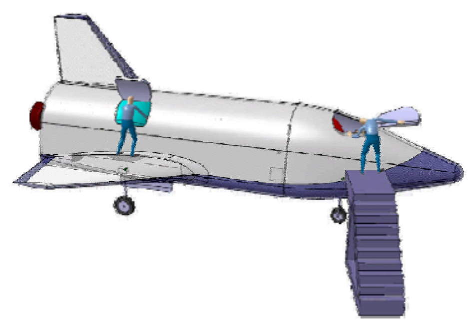
ESTEC Cost Engineering and Launcher Cost Estimating:

- **Ariane 5**
- **Vega**
- **Soyuz in Kourou**
- **Reusable Launch Vehicle studies: FESTIP, FLTP, FLPP**
- **ESTEC** internal study for a Medium Launch Vehicle
- ESTEC Concurrent Design Facility studies: **Heavy Lift Launch Vehicle, Socrates, E-Vega**
- **Mars Direct ESA/NASA MSFC Cost Engineering study** case estimate for Mars Direct Ares launcher: results similar to those prepared by NASA with NASA tools (ISPA 2004).







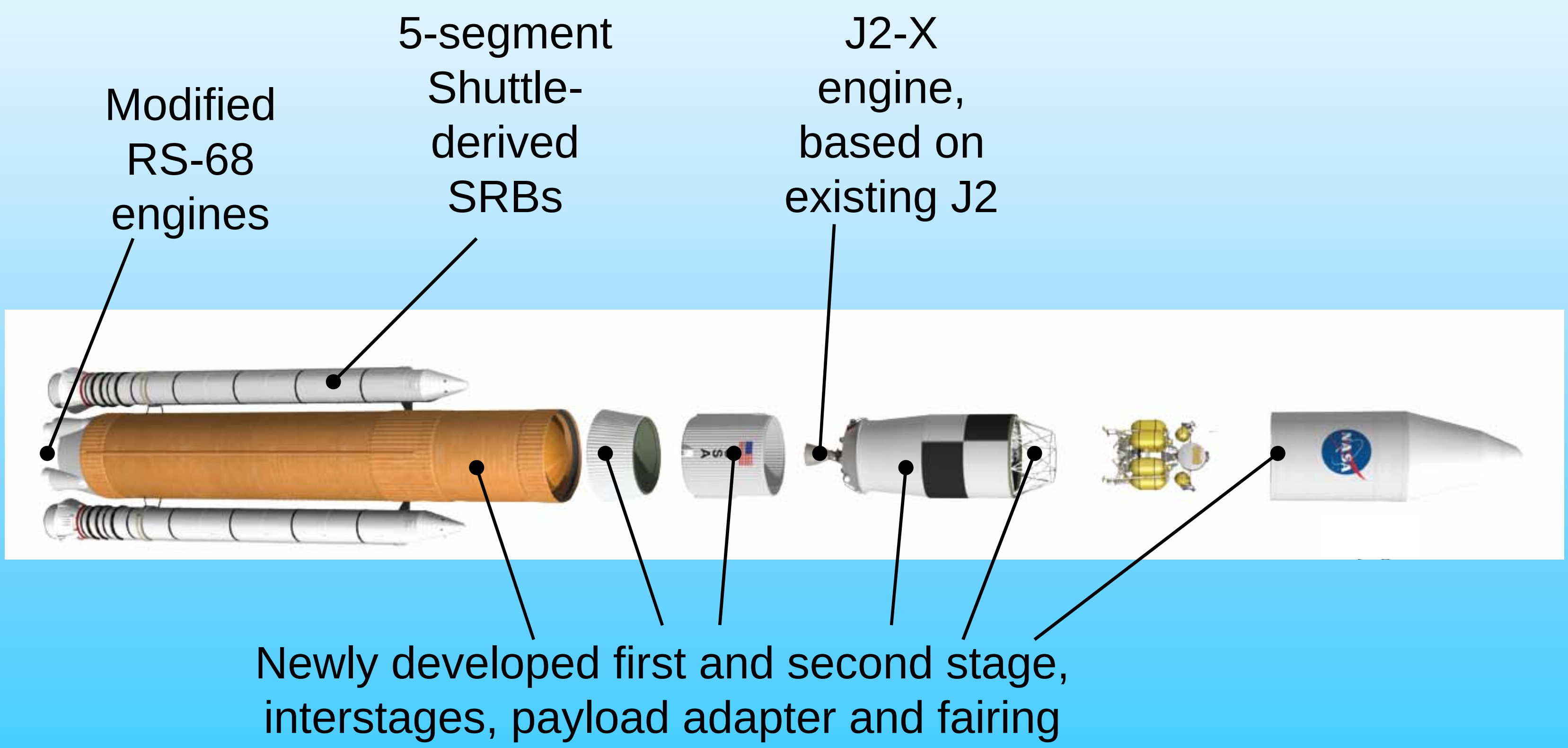
New Heavy Launchers

- **Heavy Launchers (probably) needed for future Moon & Mars missions.**
- **Cost reference is basically only Saturn V, but it has been a long time since Saturn V was last flown.**
- **Cost estimate models based on Saturn V development and launch cost may not accurately predict the effects of the current state of technology or development and production methods.**
- **Recent launchers such as Ariane V are good references for the current state of the art, but are significantly smaller than Saturn V: Using cost models based on their data to estimate heavy launcher cost requires extrapolation.**

ARES V used to compare various cost models

ARES V:

- **New NASA concept**
- **Partially based on Shuttle technology**



Cost Models Compared

Historical models, for heavy launcher largely based on Saturn V:

- **TRANSCOST** publicly available model based on historical data on many launchers + ESA enhancements & additions – Reproduces actual historical Saturn V development cost within 10%. (CERS for operations not included in Transcost added by ESA Cost Engineering)

Recent ESA models based on data for modern, recently developed launchers:

- **ESA Launcher Partial Development Cost Model (LPDCM)** internal model for estimating the cost of modifications and derivatives, mostly based on Ariane 5 and Vega data.
- **ESA launcher development and production cost estimation relationships**, internal models mostly based on Ariane 5 and Vega data, for full development and recurrent production cost estimates (LPDCM ratios used for modification estimates).

  Both models mostly developed by Ivan Auber

- **Results compared with "Longfellow launcher" (very similar to ARES V) estimate of US Congressional Budget Office** published in "Alternatives for Future U.S. Space-Launch Capabilities", October 2006.

ARES V estimates comparisons: Development in M€2006

DEVELOPMENT including First Flight Model

Total Launcher	Transcost + additions	ESA CERs	ESA LPDCM	CBO estimate
Total Development Cost	27,000	9,200	9,100	6,100
Total Development Cost excl. SRB and J-2X (because developed under Ares I programme)	24,830	8,160	8,210	?

- ESA results similar, but significantly higher than CBO estimate (no details in CBO estimate shown, so unknown what causes difference).
- Transcost gives very high cost result, mostly due to high estimates for the
  1. **Stages** and **Engines**
  2. to a lesser extent also for **Solid Rocket Boosters**.

ARES V Stage Development Cost

- Dramatic differences between Transcost and other models.
- Number of tests and prototypes similar in all models; Saturn V first stage development included only one full scale static burn test.
- Transcost model for large stages driven by old developments such as the Saturn V stages.
- ESA models stretched for ARES V estimates: Ariane V main stage 160 tons of propellant, ARES V first stage has 1400 tons, second stage 230 tons

Reasons for large estimate differences:

1. Transcost stage CERs includes cost for new large production and test facilities and tools, which the ESA models do not include (in comparison cost for test facilities deducted from Transcost results, but cost for production facilities and tools unknown).
2. Differences in 1960’s and current technology, development procedures etc., similar to those seen for rocket engines (later in this presentation)?

ARES V Engine Development Cost

Engine development cost for large part driven by the number of test engines and number of ground tests.

For the Saturn V F-1A:

- A total of 56 equivalent development engines were tested *
- 2,771 production and R&D firing tests of single engines *
- 34 tests of the 5-engine cluster (first stage configuration) *

For the Space Shuttle SSME:

- A total of 730 tests before the first Space Shuttle launch **.

ESA CERs and LPDCM defaults based on modern engine developments:

- Typically 4 to 10 prototypes (US RS-68: 8 new and 4 rebuilt)
- Typically 100 – 200 engine tests (258 for European Vulcain-1, **183 for US RS-68**, 140 for Japanese LE-7)

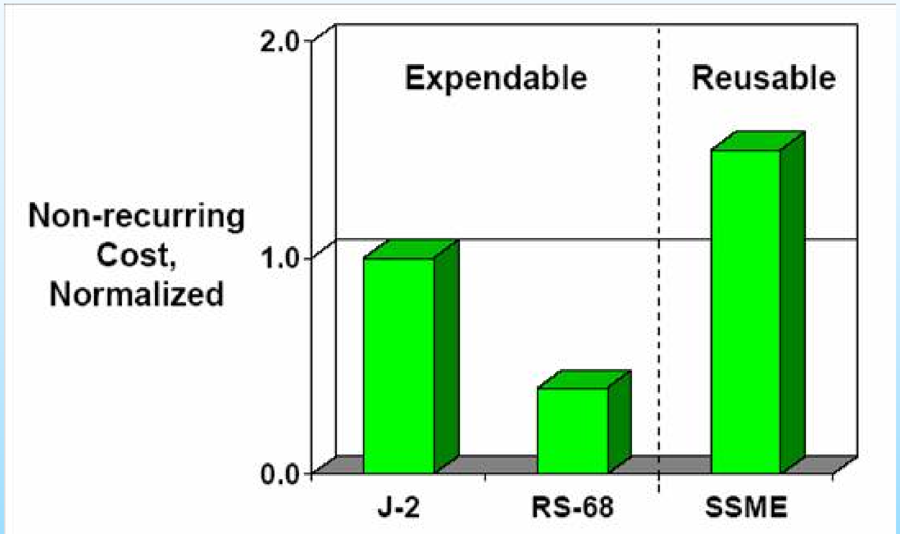
=> Number of tests for modern first stage engines much lower than for Saturn V F-1 and SSME (also for very large RS-68)!

*: Thunder in a bottle, Dwayne A. Day, Spaceflight vol 48, October 2006

**: Transcost 7.1 Handbook of Cost Engineering, TCS, 2006, page 36

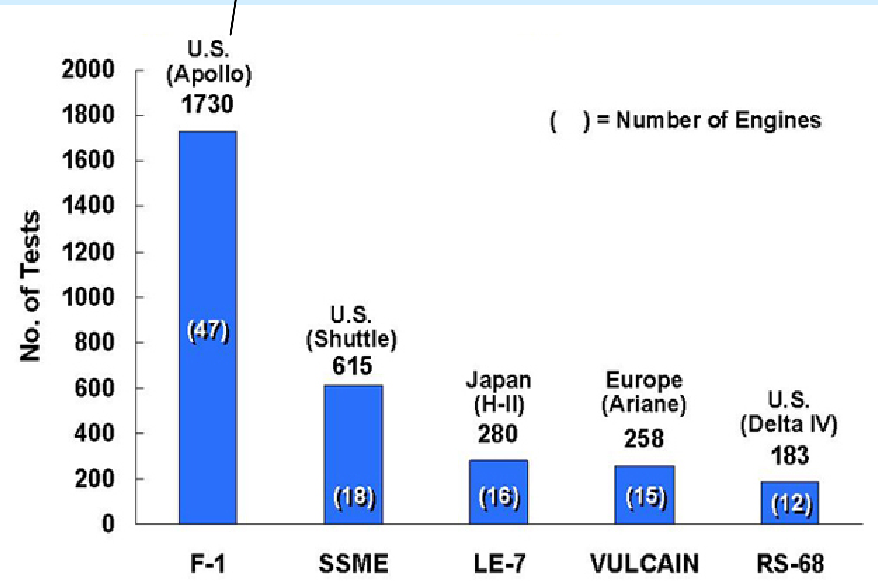
ARES V Engine Development Cost

RS-68 according to Pratt and Whitney Rocketdyne:



From "RS-68 Engine Development Program – A Lean Retrospective", T. Eastland, Pratt and Whitney Rocketdyne

Actually more: 2,771 production and R&D firing tests of single engines + 34 tests of the 5-engine cluster (first stage configuration)



# of Tests for First Flight Certification

From "Evolved Expandable Launch Vehicle System: RS-68 Main Engine Development", D. Conley et al., 53rd International Astronautical Congress, 2002

ARES V Engine Development Cost

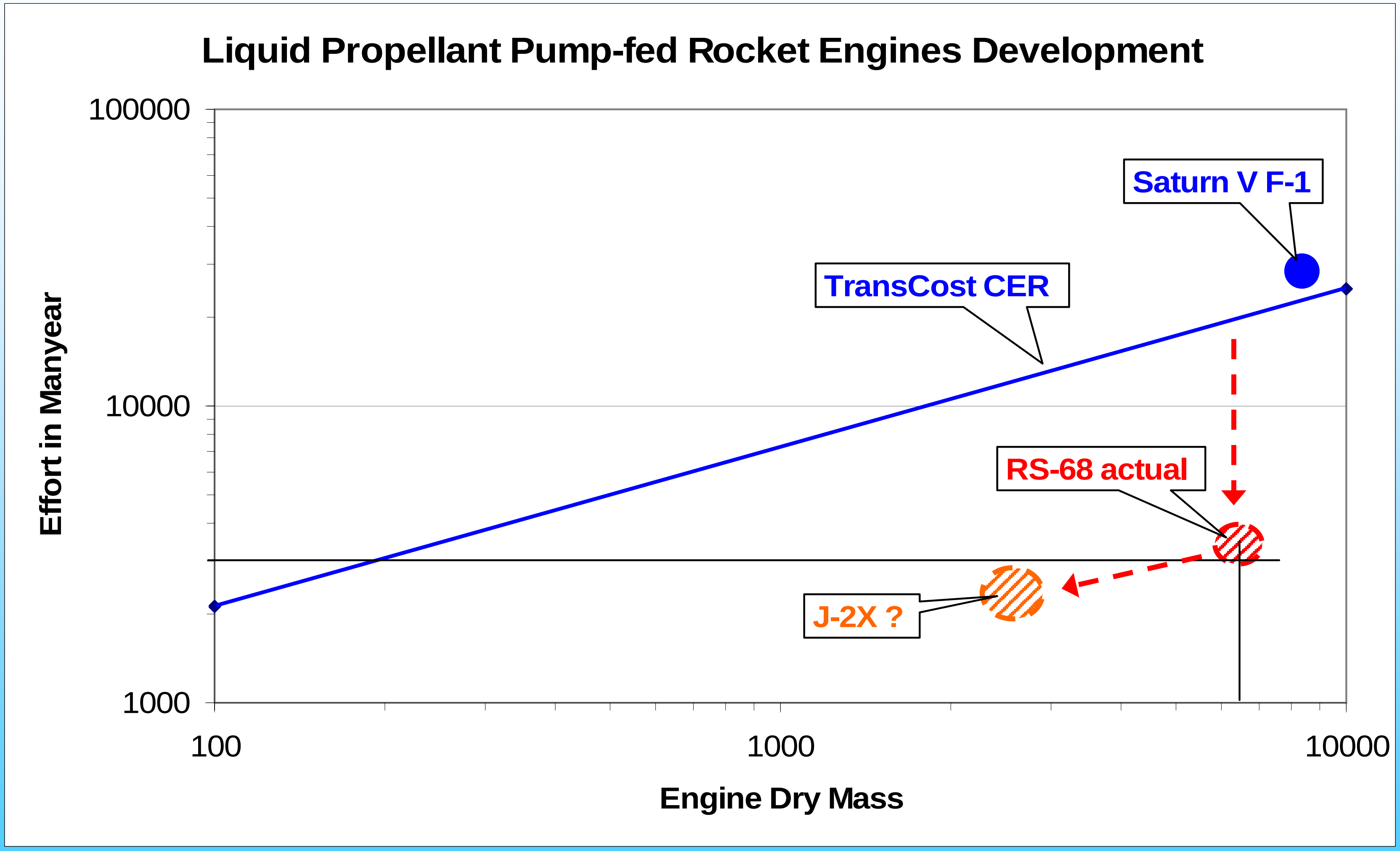
- For large engines, the Transcost development cost model is driven by historical, “old way of doing business” Saturn V and SSME data, and hence also its cost estimate results for the RS-68.

- For medium sized engines, the Transcost development cost model is driven by the J-2 (Saturn V), but also more recent Vulcain (Ariane V) and LE-7 (H-II) data.

- RS-68 development demonstrates that the development cost for new large engines like RS-68 and maybe J-2X can be **30%** of cost for large engines in the 1960’s (such as the Saturn V F1)! **This is in line with ESA CERs and LPDCM for modern engines, in comparison to Transcost results**.

- However, the RS-68 is an engine optimised for simplicity; the J-2X and other new large engines may be relatively more expensive to develop; in this case the ESA CERs and LPDCM extrapolation may give too optimistic results.

ARES V Engine Development Cost



ARES V Engine Development Cost

Check of influence of number of prototypes and tests on cost

- Transcost CERs do not include the number of prototypes and tests as an input parameter, therefore Saturn V F-1A parameters used in the ESA models:
- Similar philosophy for Second stage engine, but with somewhat less prototypes and tests because for a 1-engine stage.

Ares V 1st and 2nd stage engine development with Saturn V-like prototypes and test philosophy:

Total Launcher	Transcost + additions	ESA CERs	ESA LPDCM
1st stage cryogenic engines	1,500	1,100	1,100
2nd stage cryogenic engines	1,300	1,100	1,100

Now the results are much more similar => It appears that the high Transcost engine development cost estimates are indeed for an important part a result of the build-in very high numbers of prototypes and extensive test philosophy.

ARES V SRB Development Cost

- ESA CERs estimate for SRB development based on a single CER; LPDCM is much more sophisticated, allowing the setting of many parameters. This explains the difference between the ESA CER result and the LPDCM result for SRBs.

- Difference between ESA CERs & LPDCM and Transcost much smaller than for Liquid Propellant engines.

- For large SRBs, the Transcost development cost model is driven by Space Shuttle and Ariane 5 booster data, and hence also its cost estimate results for the modified ARES V booster.

- ESA CERs & LPDCM driven by Ariane 5 booster and Vega solid propellant stages data. Vega stages development cost indicate large development cost savings for modern SRM developments.

Vega

ARES V SRB Development Cost

- Lower number of expected test firings for new SRBs is a partial reason for the lower estimates of the ESA CERs and LPDCM:
  - 7 test firings before the Space Shuttle first flight *;
  - 7 test firings for the Ariane 5 first flight.
  - But only 2 firing tests for each Vega launcher solid rocket stage planned.

- Data on the development of the three solid rocket stages of the Vega launcher indicates considerably lower development costs w.r.t. the Transcost trend established by previous SRM developments, even for the same number of prototypes and test firings.

- It thus appears that the development effort has decreased for new motors, both because of a lower number of prototypes & test firings, and overall more efficient development techniques. However, the Vega stages are small in comparison to the ARES V SRBs => extrapolation of this development cost reduction valid for large boosters?

* : http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/sts-cron.html

ARES V estimates comparisons: Recurrent Flight Model 1

LAUNCH PRICE FIRST RECURRENT FM				
Total Launcher	Transcost + additions	ESA CERs	ESA Launch Price CER	CBO estimate
Total Launcher Production	1,120	430	850	420
Operations and Margins	570	610		420
Total Recurring Cost	1,690	1,040	850	840

- ESA detailed estimate higher than CBO estimate, ESA simple CER model in line with CBO estimate.
- Transcost gives very high cost result, mostly due to high estimates for the **Stages** and **Engines**.

  However, this time no high estimates for **Solid Rocket Boosters**.

ARES V Stage Production Cost

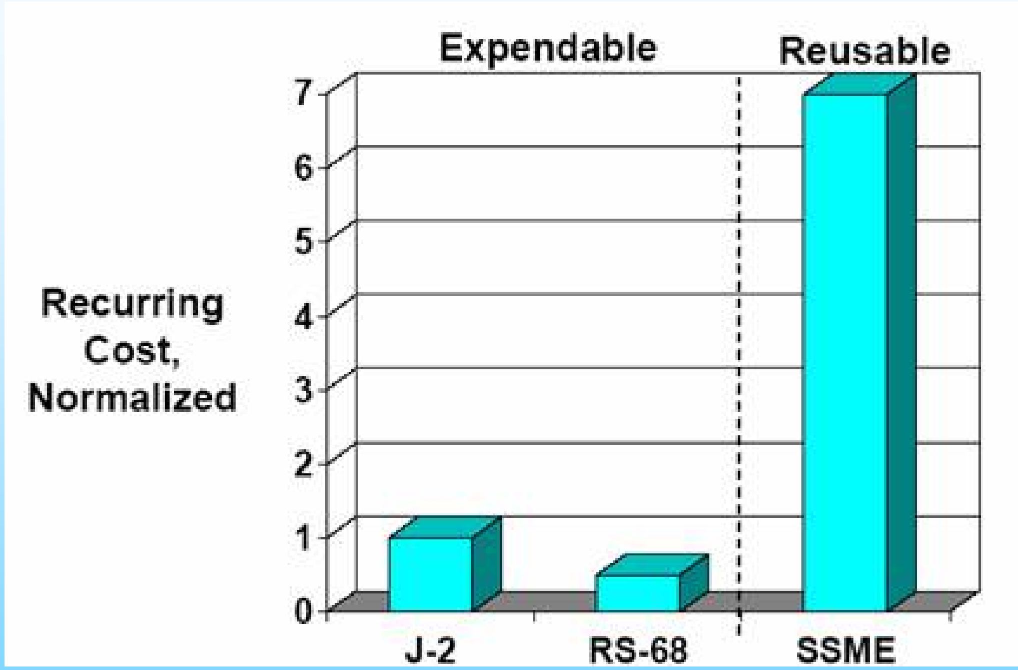
- Dramatic differences between Transcost and ESA CERs.
- Transcost model for large stages driven by old developments such as the Saturn V stages.
- ESA models stretched for ARES V estimates: Ariane V main stage 160 tons of propellant, ARES V first stage has 1400 tons, second stage 230 tons

Reasons for large estimate differences:

- Differences in 1960's and current production methods?
- Easier-to-produce designs for modern stages?
- Other?

ARES V Engine Recurrent Cost

RS-68 according to Pratt and Whitney Rocketdyne:



From “RS-68 Engine Development Program – A Lean Retrospective”, T. Eastland, Pratt and Whitney Rocketdyne

NASA: Recurrent cost for modified RS-68 for Ares V about 20 M$ per engine* = 15 M€ x 5 = 75 M€ for the First Stage. This is in line with the ESA CERs result.

* http://www.nasa.gov/home/hqnews/2006/may/HQ_06226_RS-68_ENGINE.html

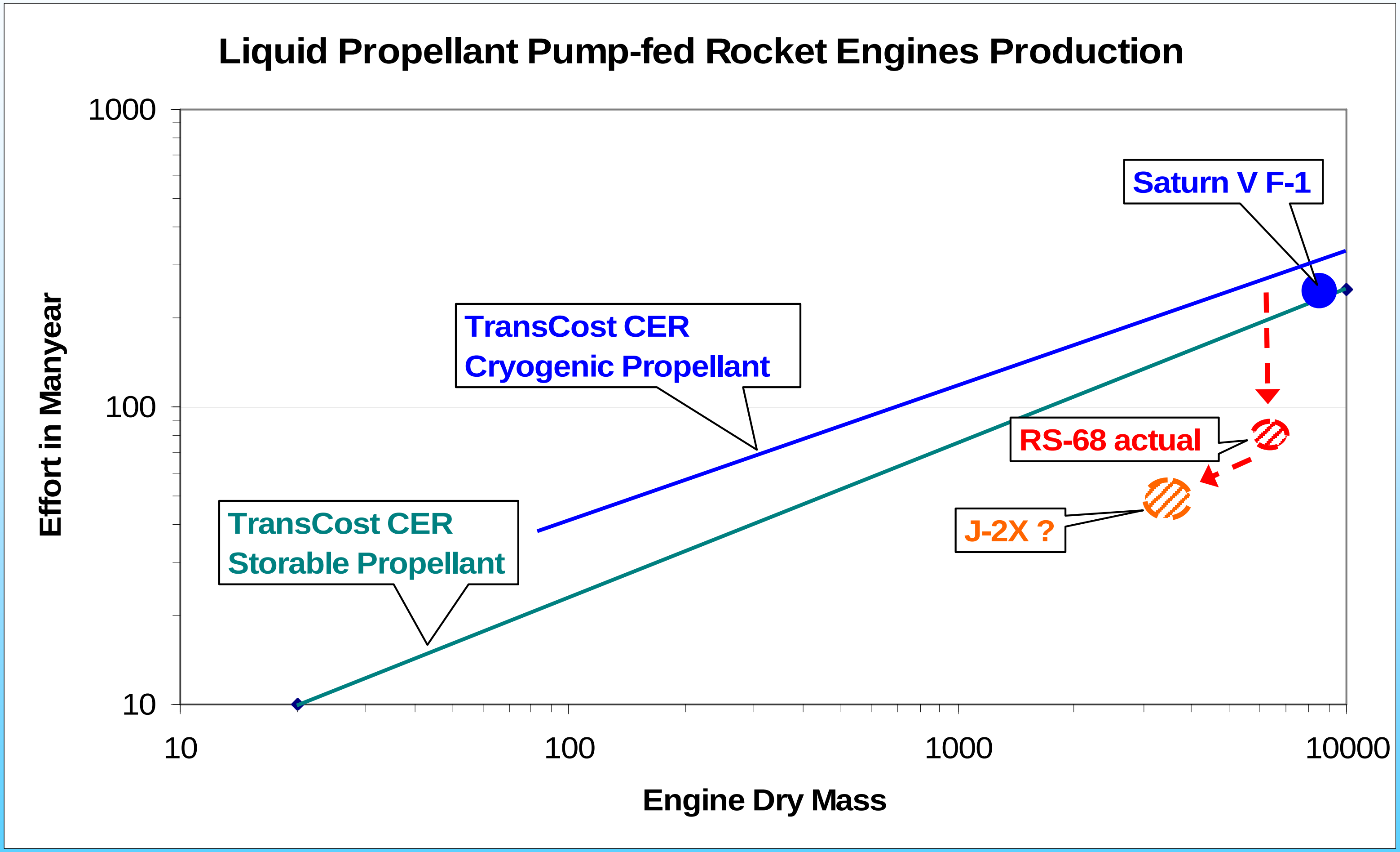
ARES V Engine Recurrent Cost

- The Transcost recurrent cost model is driven by historical, "old way of doing business" Saturn V and SSME data, and hence also its cost estimate results for the RS-68.

- RS-68 recurrent cost demonstrates that the cost for a new large engines like RS-68 and J-2X can be **25% to 30%** of cost for large engines in the 1960's (such as the Saturn V F1)! **This is in line with ESA CERs for modern engines**.

- However, the RS-68 is an engine optimised for simplicity; the J-2X and other new large engines may be relatively more expensive to produce; in this case the ESA CERs extrapolation may give too optimistic results.

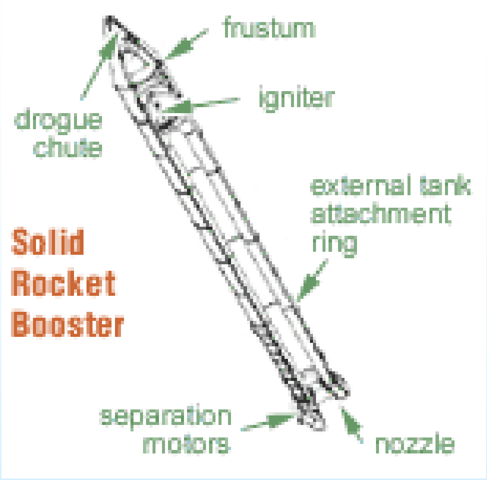
ARES V Engine Recurrent Cost



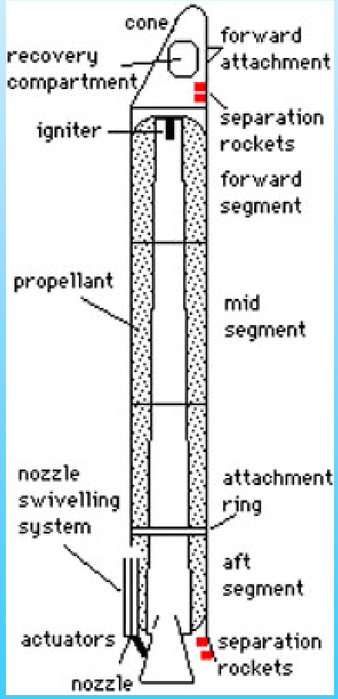
ARES V SRB Recurrent Cost

Not much difference in the SRB Recurrent Cost estimates of the various models:

- ARES V SRB is similar to Space Shuttle SRB and Ariane 5 booster;
- Recurring cost of Space Shuttle and Ariane 5 boosters well in line with each other: Transcost and ESA CERs give similar results for similar boosters;
- In comparison to liquid propellant rocket engines, large SRBs offer little possibility for simplification of design and production.
- Continuation of established large SRB production methods (assumed) leads to ARES V SRB cost estimates that are in line with those for the Shuttle and Ariane 5.



Shuttle SRB



Ariane 5 booster

Conclusions

- Cause of differences in development and production cost for stages (without engines) not fully clear but at least partly due to more efficient designs and production methods.
- ESA model outputs for Engine Development and Recurrent Cost in line with RS-68; extrapolation from Ariane 5 seems valid**.**
- However, the RS-68 is an engine optimised for simplicity; the J-2X and other new large engines may be relatively more expensive to develop and produce; in this case the ESA models extrapolation may give too optimistic results.
- Transcost CERs based on “old way of doing business”, specifically the much higher number of engine prototypes and tests required, and the higher production cost.
- However, ESA models fully valid for very large launchers? Less costly development and production w.r.t. Saturn V should be possible, but to the full extent indicated by modern developments for smaller launchers?
- CBO ARES V development estimate low, even in comparison to ESA models results: too optimistic? CBO recurrent recurrent launch cost also on the low side.