Exploration Systems Cost-Risk & Beyond

presented to
NASA RISK MANAGEMENT CONFERENCE
7 DEC 05

David R. Graham

OUTLINE

- Cost-Risk
  - Players
  - Identifying medium and high-risk WBS elements
  - Assessment
  - Analysis
- ESAS Cost-risk
  - FY 06-11
  - FY 06-18
- Continuous Cost-Risk Management

Players in Cost-Risk

- Estimators know the uncertainty in cost methodology
- Engineers and those trained and involved in performing Continuous Risk Management (CRM) on the project
  - They understand the risks in:
    - CER input parameters values (e.g., weight)
    - Technology state of the art (TRL)
    - Designs that use the technologies
    - Engineering necessary to implement the technologies used in the designs
    - Adequacy of the schedule to design and implement the technologies
    - Integration involved at the box, component, subsystem and system levels
    - ….etc.
    - Correlations between input parameters and between WBS elements

CCRM STEP 2: IDENTIFY THE RISKS

ALLOCATING FUNCTIONS TO WBS ELEMENTS

FUNCTION-TO-WBS ELEMENT MATRIX	FUNCTIONS	Solar Array	Pointing & Control	Transmitter/Receive	Power Mgmt & Dist	
WBS ELEMENTS						
Transmit Payload						
- Solar Power Collector		X	X		X	Medium Risk
- Solar Power Converter		X	X		X	High Risk
- Pointing & Control System		X	X	X	X	High Risk
- Laser Amplifier/Transmitter			X	X	X	High Risk
- Laser Transmit Antenna		X	X	X	X	Medium Risk
Receive Payload			X			
- Microwave Receive Antenna			X	X	X	Medium Risk
- Laser Receive Antenna		X	X	X	X	High Risk
- Tracking & Control system			X	X	X	High Risk
- Laser Conditioning Receiver			X	X	X	High Risk
- Laser Rectifier/Converter			X	X	X	High Risk
- Flywheel Storage System			X	X	X	Medium Risk

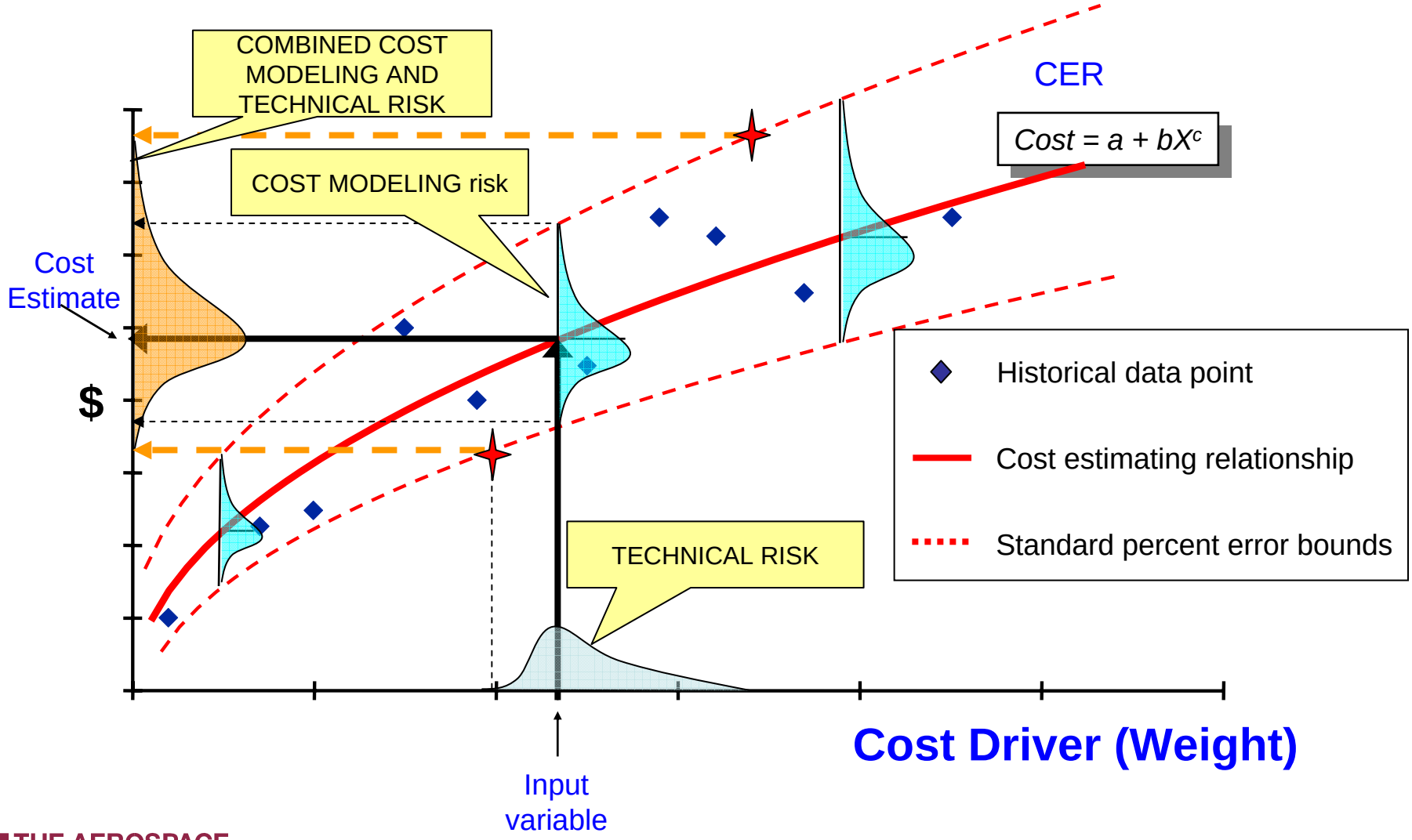
Cost-Risk Assessment & Analysis

- Assessment
  1. ***Cost model risk***
     - Cost estimators handle this
  2. ***Input parameter risk***
     - Engineering assessment needed
  3. ***Key Engineering Parameter Performance (KEPP) risk***
     - Engineering assessment needed
     - 3 WBS element risk profiles (pessimistic, optimistic & reference) evaluated in terms of cost-risk drivers
  4. ***Correlation risk***
     - Engineering/cost estimator assessment needed
- Analysis
  - Convolve all distributions for “S”-curve (CDF)

Cost-Risk Assessment

1. ***Cost model risk***
   - Accomplished in ESAS FY 06-11 cost-risk
2. ***Input parameter risk***
   - Accomplished in ESAS FY 06-11 cost-risk

Cost Model and Input Parameter Risk
Cost Quantification



Cost-Risk Assessment (cont)

3. Key Engineering Parameter Performance (KEPP) risk

- **Partially** Accomplished in ESAS FY 06-11 cost-risk
  - Adds cost-risk impacts due to TRL, Design/Engineering, Integration, Requirements Stability, Complexity, etc., risks
  - Relative Risk Weighting process can capture these risks
- ***A Key Engineering Performance Parameter is a technical or operational parameter that can be described as a requirement***

Key Engineering Performance Parameters[1] (KEPP) Examples

- KEPPs for new electronic component for a S/C
  - Dynamic load resistance
  - Operating voltage
  - Power regulation
  - Radiation resistance
  - Emissivity
  - Component mass
  - Operating temperature range
  - Operating efficiency
- KEPPs for a Laser/Amplifier Transmitter
  - Wave front sensing
  - Wave generation
  - Mirror coatings and gratings
  - Autonomous resonator alignment
  - Bore sighting
  - Electrical power generation

[1]The Technology Puzzle: Quantitative Methods for Developing Advanced Aerospace Technology; Liam Sarsfield (RAND)

RRW Implemented in Excel

(Degree System's KEPPs Impacted by Cost-Risk Drivers in each Scenario)

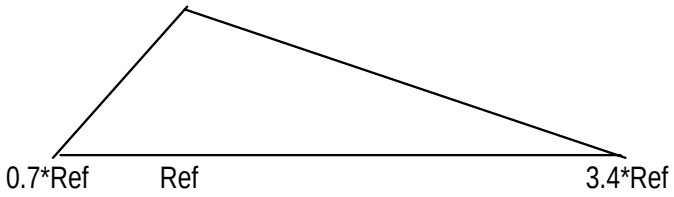
	COST-RISK DRIVERS					
	TRL	Des/Eng	Schedule	Integration	Reqts Stab	
(Driver Weights) →	0.2	0.3	0.15	0.2	0.15	**Risk Score**
WBS Scenarios: Pessimistic	0.048	0.111	0.058	0.049	0.080	**0.345**
WBS Scenarios: Reference	0.020	0.027	0.026	0.016	0.014	**0.102**
WBS Scenarios: Optimistic	0.014	0.023	0.007	0.016	0.011	**0.071**

Intensities	TRL	Des/Eng	Schedule	Integration	Reqts Stab
Very High	0.397	0.370	0.385	0.442	0.534
High	0.240	0.220	0.262	0.243	0.216
Moderately High	0.139	0.150	0.171	0.142	0.094
Moderate	0.099	0.089	0.078	0.081	0.070
Moderately Low	0.070	0.075	0.049	0.047	0.044
Low	0.033	0.054	0.034	0.026	0.026
Very Low	0.022	0.042	0.021	0.019	0.016

Ratio Scale Numbers from AHP

Pess/Reference Ratio: 3.4

Opt/Reference Ratio: 0.7



Cost-Risk Assessment
(cont)

4. Correlation risk

- Accomplished in ESAS

CORRELATION

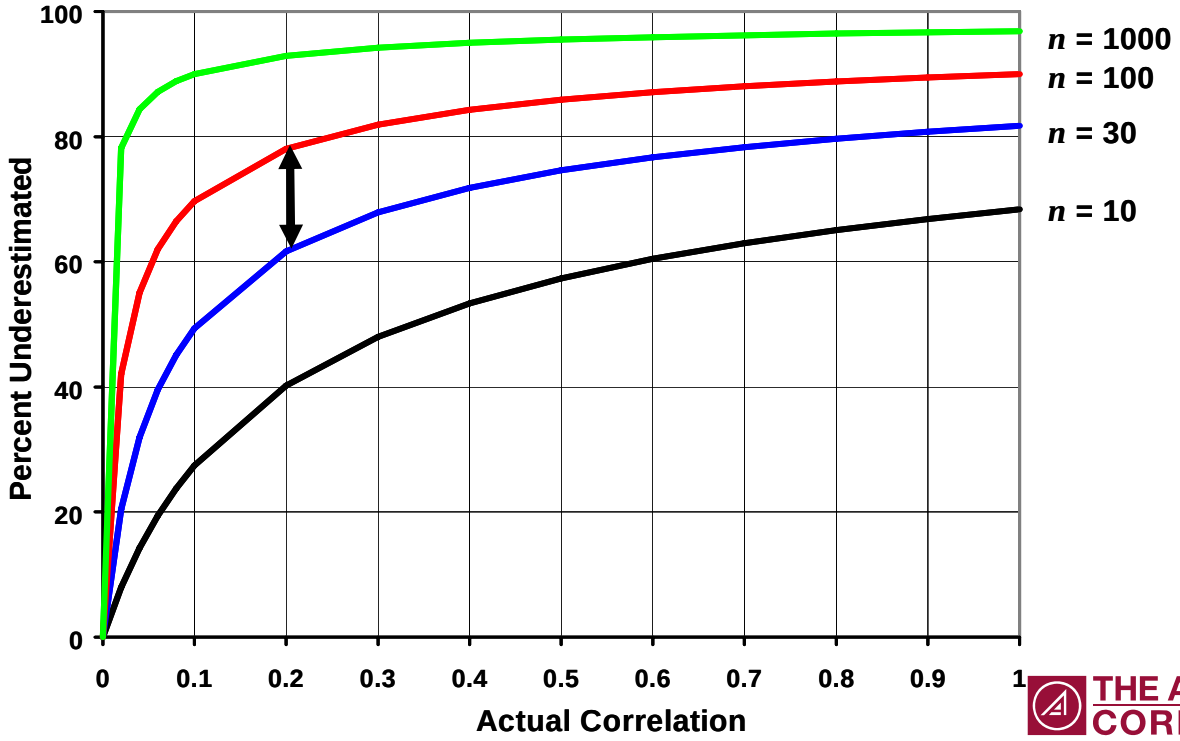
- What is Correlation?[2]
  - A measure of association between two variables
  - It measures how strongly the variables are related, or change, with each other
- Engineers and CRM specialists can assist cost estimators in identifying and quantifying correlation between WBS elements

[2] www.statlets.com/usermanual/glossary.htm

Correlation

- Dr. Stephen Book (MCR) plotted the theoretical underestimation of percent total cost standard deviation (y-axis) when correlation (x-axis) is assumed to be zero rather than its true value, ρ.
  - In cost estimates we would underestimate % SD ~60%-80% if we ignored correlation and it was actually 0.2

% Underestimated Theoretical Total Cost Standard Deviation



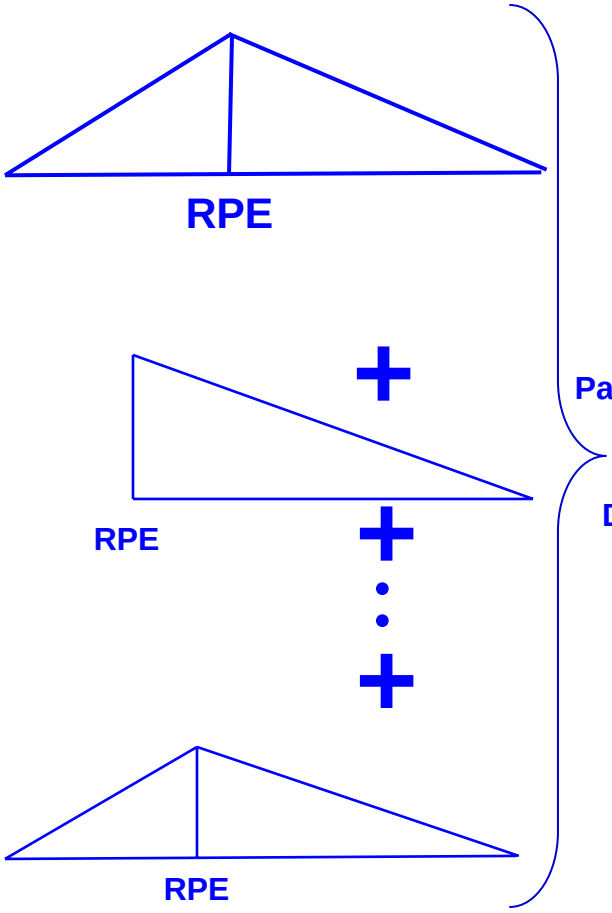
From: 1999 Cost Risk Analysis Seminar, Manhattan Beach, CA

Cost-Risk Analysis

- Analysis
  - –Convolve all distributions for “S”-curve (CDF)

Cost-Risk Analysis: Convolution

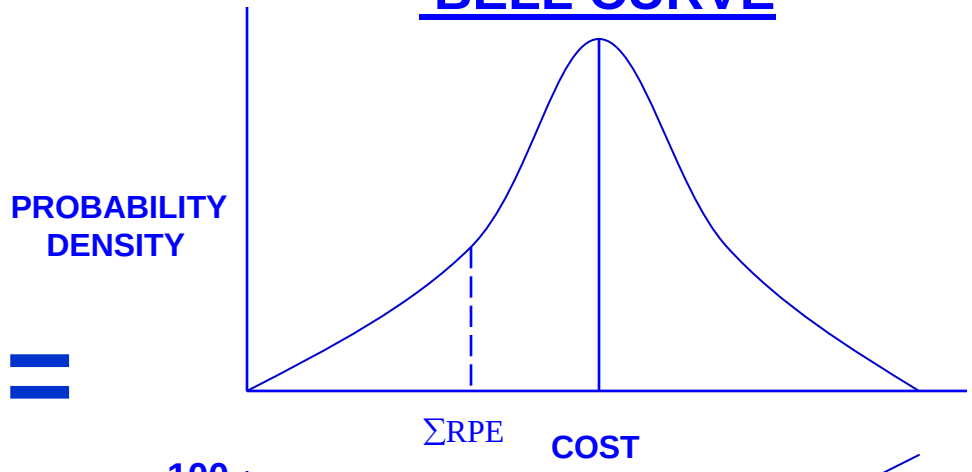
CORRELATED SUBSYSTEM & SYSTEM COST DISTRIBUTIONS:



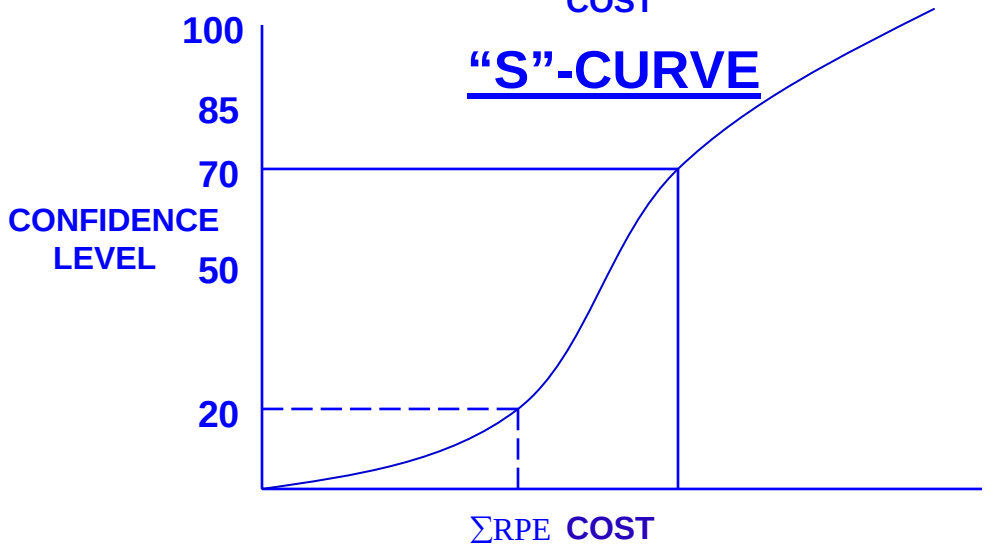
CER, Parameter Input, and KEPP Cost-Risk Distributions

=

SUMMARY COST DISTRIBUTIONS: BELL CURVE



"S"-CURVE



Cost-Risk Applied to Exploration Systems

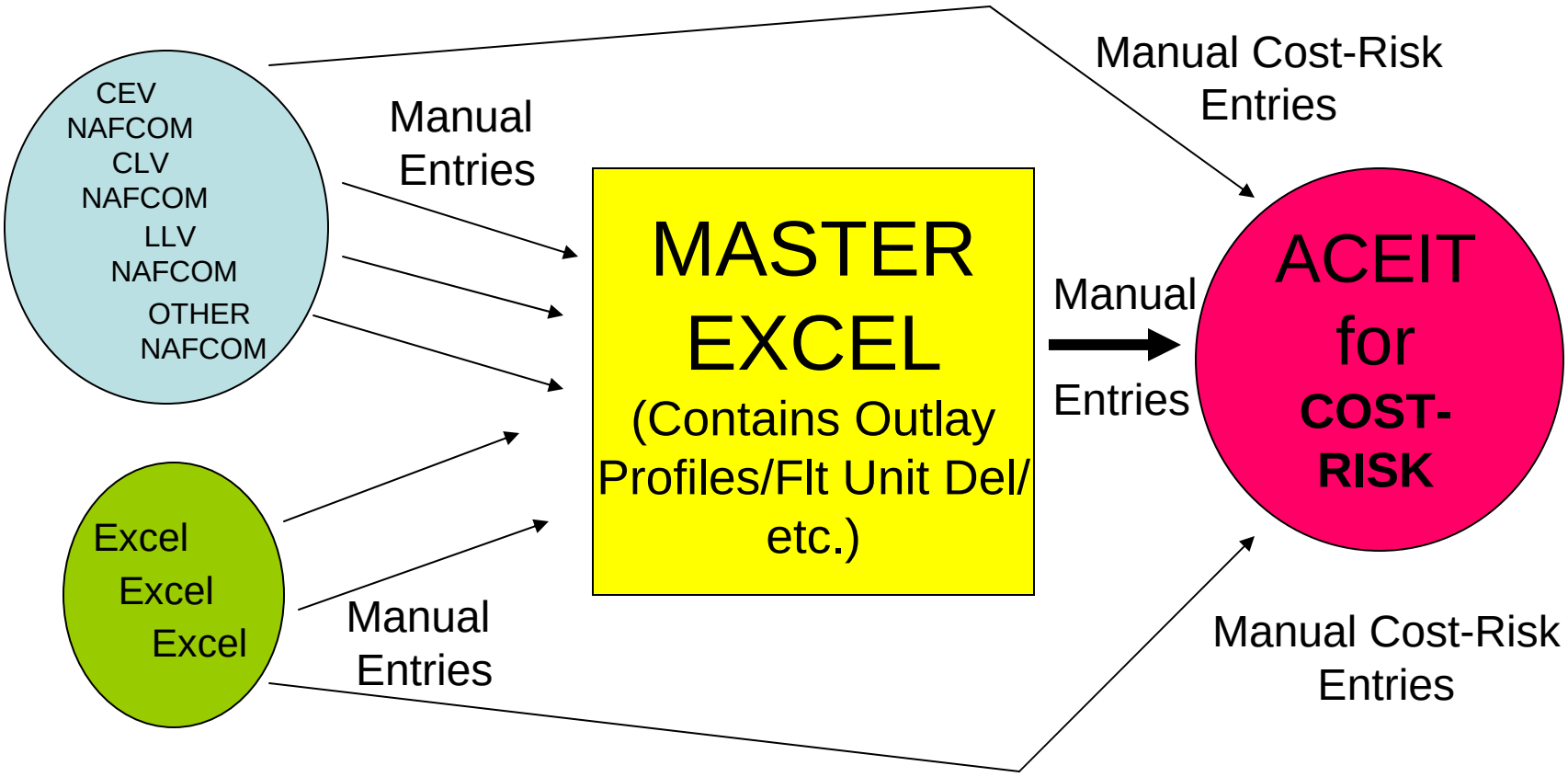
ESAS Cost Estimating Approach

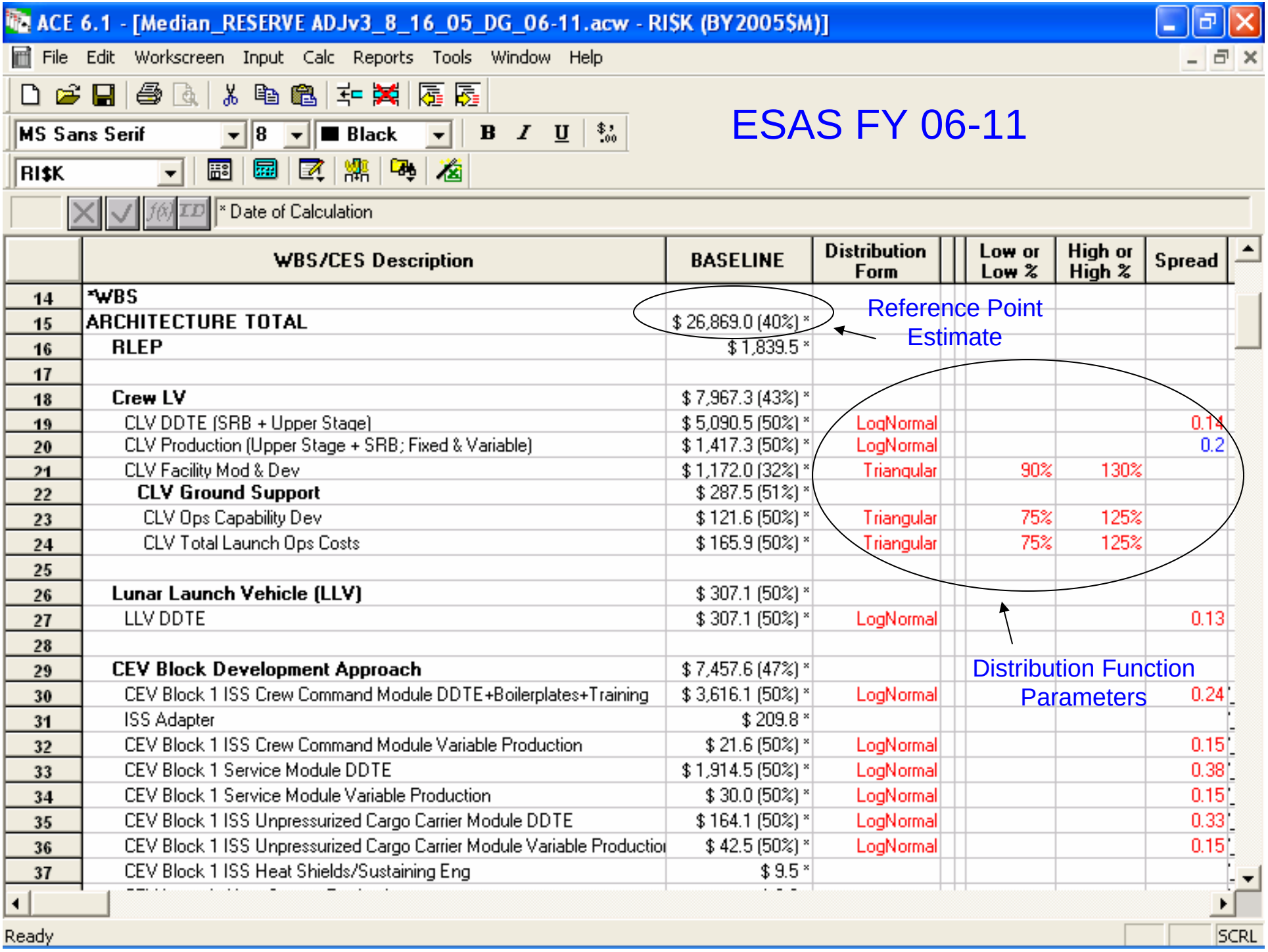
- **Cost estimates generated by responsible NASA field centers**
  - GRC: Lunar power systems
  - JSC: Crew Exploration Vehicle, lunar surface systems, mission operations/infrastructure
  - KSC: Launch operations/infrastructure
  - MSFC: Launch systems
  - SSC: Engine testing
  - HQ: Integration
- **All cost estimates vetted by NASA HQ for completeness and credibility**
  - Also reviewed by External Review Team and Graybeard Review Team
- **“Full Cost” effects included**
  - Civil Service, support contractors, service pools, G&A

ESAS Cost Estimating Approach
(cont)

- **Probabilistic cost risk analysis used to recommend final cost reserve levels (65% confidence level for estimates through 2011 budget horizon totaling $31.3B)**
  - 65% confidence level is consistent NPR 7120.5C policy guidance
  - 80% confidence as recommended by Defense Science Board, is $32.1B
    - Most of cost risk is post 2011
- **Cost estimates reflect demonstrated aerospace productivity improvements since Apollo**
- **Otherwise, cost were estimated conservatively and assume NASA business as usual**
  - NASA intends to actively pursue commercial/international participation in exploration, which could reduce cost, allow schedule accelerations or allow increased content
  - ESAS SDV estimated costs were consistently higher than Shuttle Industry Team

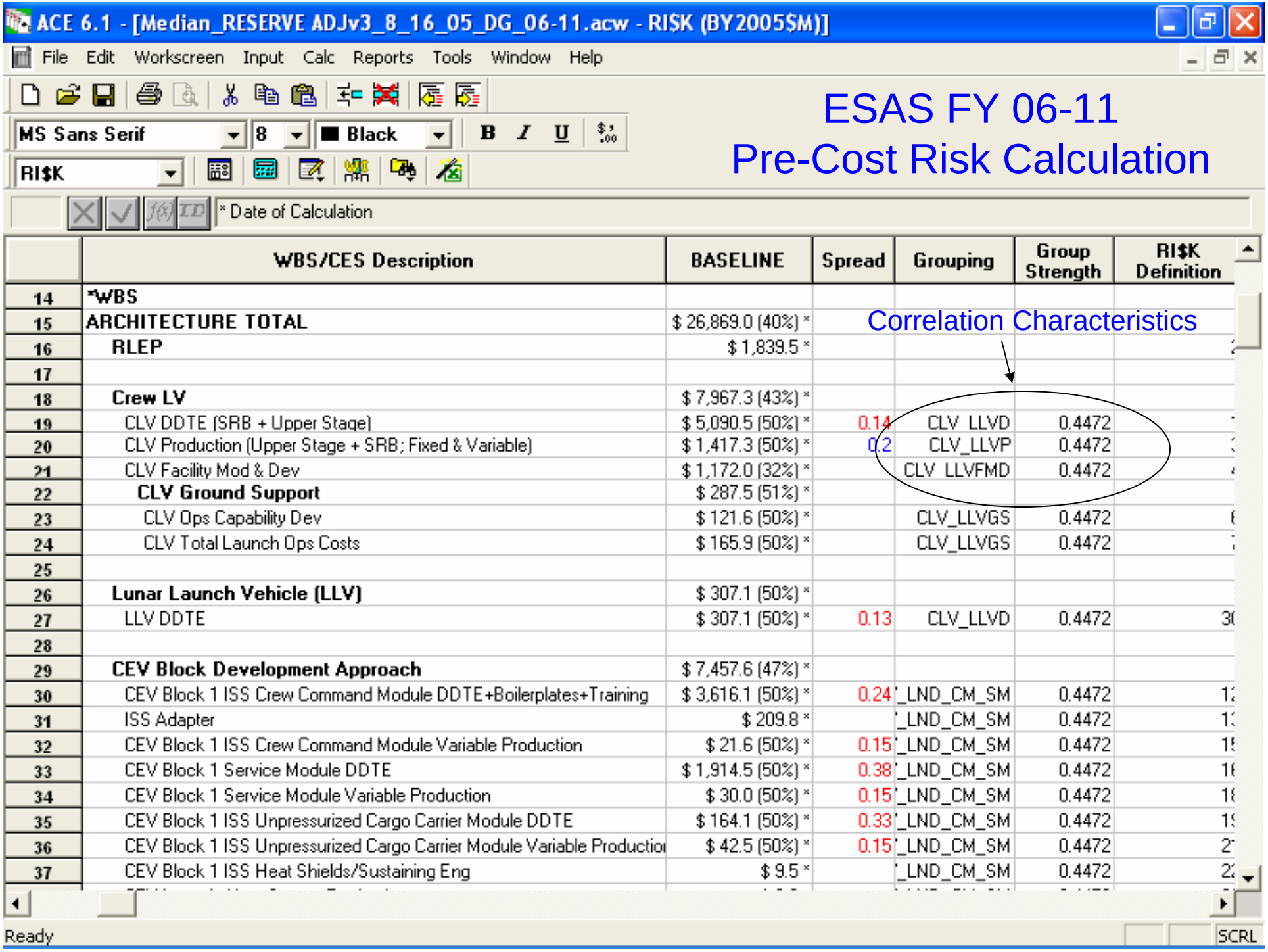
ESAS STUDY COST-RISK PROCEDURE



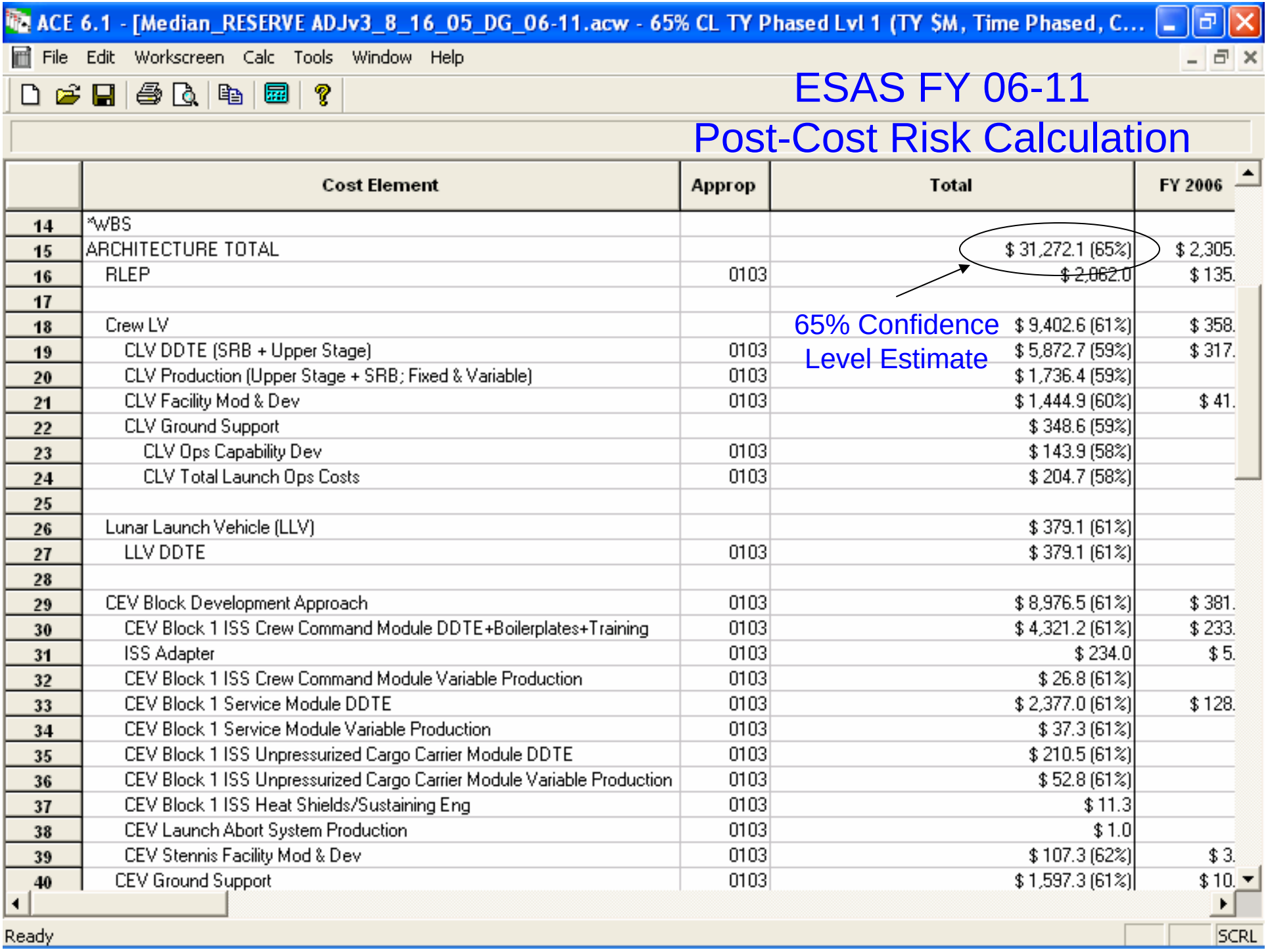


	WBS/CES Description	BASELINE	Distribution Form	Low or Low %	High or High %	Spread
14	*WBS					
15	ARCHITECTURE TOTAL	$ 26,869.0 (40%) *				
16	RLEP	$ 1,839.5 *				
17						
18	Crew LV	$ 7,967.3 (43%) *				
19	CLV DDTE (SRB + Upper Stage)	$ 5,090.5 (50%) *	LogNormal			0.14
20	CLV Production (Upper Stage + SRB; Fixed & Variable)	$ 1,417.3 (50%) *	LogNormal			0.2
21	CLV Facility Mod & Dev	$ 1,172.0 (32%) *	Triangular	90%	130%	
22	CLV Ground Support	$ 287.5 (51%) *				
23	CLV Ops Capability Dev	$ 121.6 (50%) *	Triangular	75%	125%	
24	CLV Total Launch Ops Costs	$ 165.9 (50%) *	Triangular	75%	125%	
25						
26	Lunar Launch Vehicle (LLV)	$ 307.1 (50%) *				
27	LLV DDTE	$ 307.1 (50%) *	LogNormal			0.13
28						
29	CEV Block Development Approach	$ 7,457.6 (47%) *				
30	CEV Block 1 ISS Crew Command Module DDTE+Boilerplates+Training	$ 3,616.1 (50%) *	LogNormal			0.24
31	ISS Adapter	$ 209.8 *				
32	CEV Block 1 ISS Crew Command Module Variable Production	$ 21.6 (50%) *	LogNormal			0.15
33	CEV Block 1 Service Module DDTE	$ 1,914.5 (50%) *	LogNormal			0.38
34	CEV Block 1 Service Module Variable Production	$ 30.0 (50%) *	LogNormal			0.15
35	CEV Block 1 ISS Unpressurized Cargo Carrier Module DDTE	$ 164.1 (50%) *	LogNormal			0.33
36	CEV Block 1 ISS Unpressurized Cargo Carrier Module Variable Productio	$ 42.5 (50%) *	LogNormal			0.15
37	CEV Block 1 ISS Heat Shields/Sustaining Eng	$ 9.5 *				

Ready SCRL

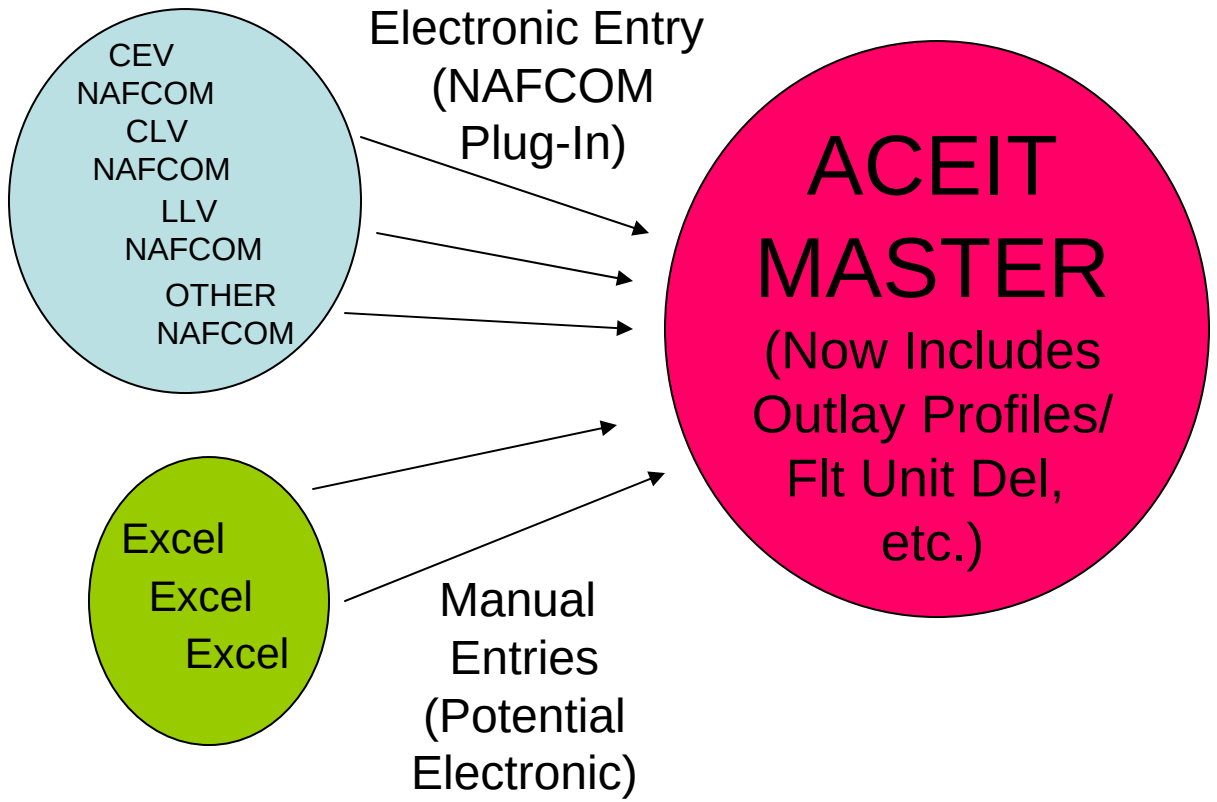


	WBS/CES Description	BASELINE	Spread	Grouping	Group Strength	RI$K Definition
14	*WBS					
15	ARCHITECTURE TOTAL	$ 26,869.0 (40%) *				
16	RLEP	$ 1,839.5 *				2
17						
18	Crew LV	$ 7,967.3 (43%) *				
19	CLV DDTE (SRB + Upper Stage)	$ 5,090.5 (50%) *	0.14	CLV_LLVD	0.4472	
20	CLV Production (Upper Stage + SRB; Fixed & Variable)	$ 1,417.3 (50%) *	0.2	CLV_LLVP	0.4472	
21	CLV Facility Mod & Dev	$ 1,172.0 (32%) *		CLV_LLVFMD	0.4472	
22	CLV Ground Support	$ 287.5 (51%) *				
23	CLV Ops Capability Dev	$ 121.6 (50%) *		CLV_LLVGS	0.4472	
24	CLV Total Launch Ops Costs	$ 165.9 (50%) *		CLV_LLVGS	0.4472	
25						
26	Lunar Launch Vehicle (LLV)	$ 307.1 (50%) *				
27	LLV DDTE	$ 307.1 (50%) *	0.13	CLV_LLVD	0.4472	30
28						
29	CEV Block Development Approach	$ 7,457.6 (47%) *				
30	CEV Block 1 ISS Crew Command Module DDTE+Boilerplates+Training	$ 3,616.1 (50%) *	0.24	'_LND_CM_SM	0.4472	12
31	ISS Adapter	$ 209.8 *		'_LND_CM_SM	0.4472	13
32	CEV Block 1 ISS Crew Command Module Variable Production	$ 21.6 (50%) *	0.15	'_LND_CM_SM	0.4472	15
33	CEV Block 1 Service Module DDTE	$ 1,914.5 (50%) *	0.38	'_LND_CM_SM	0.4472	16
34	CEV Block 1 Service Module Variable Production	$ 30.0 (50%) *	0.15	'_LND_CM_SM	0.4472	18
35	CEV Block 1 ISS Unpressurized Cargo Carrier Module DDTE	$ 164.1 (50%) *	0.33	'_LND_CM_SM	0.4472	19
36	CEV Block 1 ISS Unpressurized Cargo Carrier Module Variable Productio	$ 42.5 (50%) *	0.15	'_LND_CM_SM	0.4472	21
37	CEV Block 1 ISS Heat Shields/Sustaining Eng	$ 9.5 *		'_LND_CM_SM	0.4472	22



	Cost Element	Approp	Total	FY 2006
14	*WBS			
15	ARCHITECTURE TOTAL		$ 31,272.1 (65%)	$ 2,305.
16	RLEP	0103	$ 2,062.0	$ 135.
17				
18	Crew LV		$ 9,402.6 (61%)	$ 358.
19	CLV DDTE (SRB + Upper Stage)	0103	$ 5,872.7 (59%)	$ 317.
20	CLV Production (Upper Stage + SRB; Fixed & Variable)	0103	$ 1,736.4 (59%)	
21	CLV Facility Mod & Dev	0103	$ 1,444.9 (60%)	$ 41.
22	CLV Ground Support		$ 348.6 (59%)	
23	CLV Ops Capability Dev	0103	$ 143.9 (58%)	
24	CLV Total Launch Ops Costs	0103	$ 204.7 (58%)	
25				
26	Lunar Launch Vehicle (LLV)		$ 379.1 (61%)	
27	LLV DDTE	0103	$ 379.1 (61%)	
28				
29	CEV Block Development Approach	0103	$ 8,976.5 (61%)	$ 381.
30	CEV Block 1 ISS Crew Command Module DDTE+Boilerplates+Training	0103	$ 4,321.2 (61%)	$ 233.
31	ISS Adapter	0103	$ 234.0	$ 5.
32	CEV Block 1 ISS Crew Command Module Variable Production	0103	$ 26.8 (61%)	
33	CEV Block 1 Service Module DDTE	0103	$ 2,377.0 (61%)	$ 128.
34	CEV Block 1 Service Module Variable Production	0103	$ 37.3 (61%)	
35	CEV Block 1 ISS Unpressurized Cargo Carrier Module DDTE	0103	$ 210.5 (61%)	
36	CEV Block 1 ISS Unpressurized Cargo Carrier Module Variable Production	0103	$ 52.8 (61%)	
37	CEV Block 1 ISS Heat Shields/Sustaining Eng	0103	$ 11.3	
38	CEV Launch Abort System Production	0103	$ 1.0	
39	CEV Stennis Facility Mod & Dev	0103	$ 107.3 (62%)	$ 3.
40	CEV Ground Support	0103	$ 1,597.3 (61%)	$ 10.

PROPOSED PROCEDURE for Exploration Systems FY 06-18 COST-RISK STUDY



…and Beyond

Continuous Cost-Risk Management (CCRM)

- A cost management architecture providing:
  1. ***Identification*** of medium and high risk WBS elements, their assessment & translation of risk into cost-risk in LCCEs
     - Supports adequate budget for project
  2. ***Communication*** of identified medium and high risk WBS elements to project managers (contractor or NASA)
  3. ***Post-cost estimate tracking*** of medium and high risk WBS element cost and schedule performance Application of EVM system
     - Produces early warning of potential cost and schedule problems
     - Enables actionable intelligence for timely mitigation/management
  4. ***Updates*** of technical and cost data (including annual LCCEs)
  5. ***History*** of cost and technical data for use in updating cost models

CCRM

Continuous Cost-Risk Management

A ***System of Cost Systems*** linked together in sequence by the same risks

Risk Management

Incorporated in NPR 7120.5C

Preparation
Cost-Risk Feedback: Steps 1-5

Application
Cost-Risk Feedback: Steps 9-12

Development
Cost-Risk Feedback: Steps 6-8

CCRM
Development & Application

CCRM Step 6:
CPR Data Requirements Description

- For cost-risk feedback, the contractor or performing organization needs to be informed in the RFP/Project Plan about:
  - Medium and high-risk systems, subsystems and/or WBS elements identified initially in the cost estimate
  - EVM performance measurement requirements against these specific risky WBS elements
    - e.g., WBS element reporting levels (NPR 7120.5C)
- An EVM CPR DRD template is available on the Cost Estimating Handbook website
  - www.ceh.nasa.gov

Example of Earned Value DRD Instructions
Paragraph 1: High Risk WBS List & Reporting Criteria

1. Earned value insight (BCWS, BCWP, ACWP on Format 1 and narrative status on Format 5) for the following high risk WBS elements shall be provided every month regardless of variance percentage levels until the system program office (SPO) informs the contractor otherwise:

Power Subsystem ASIC; Solar Power Converter; Pointing & Control System Laser Amplifier/Transmitter; Laser Transmit Antenna; Microwave Receive Antenna; Laser Receive Antenna; Tracking & Control System; Laser Conditioning Receiver; Laser Rectifier/Converter; Flywheel Storage System

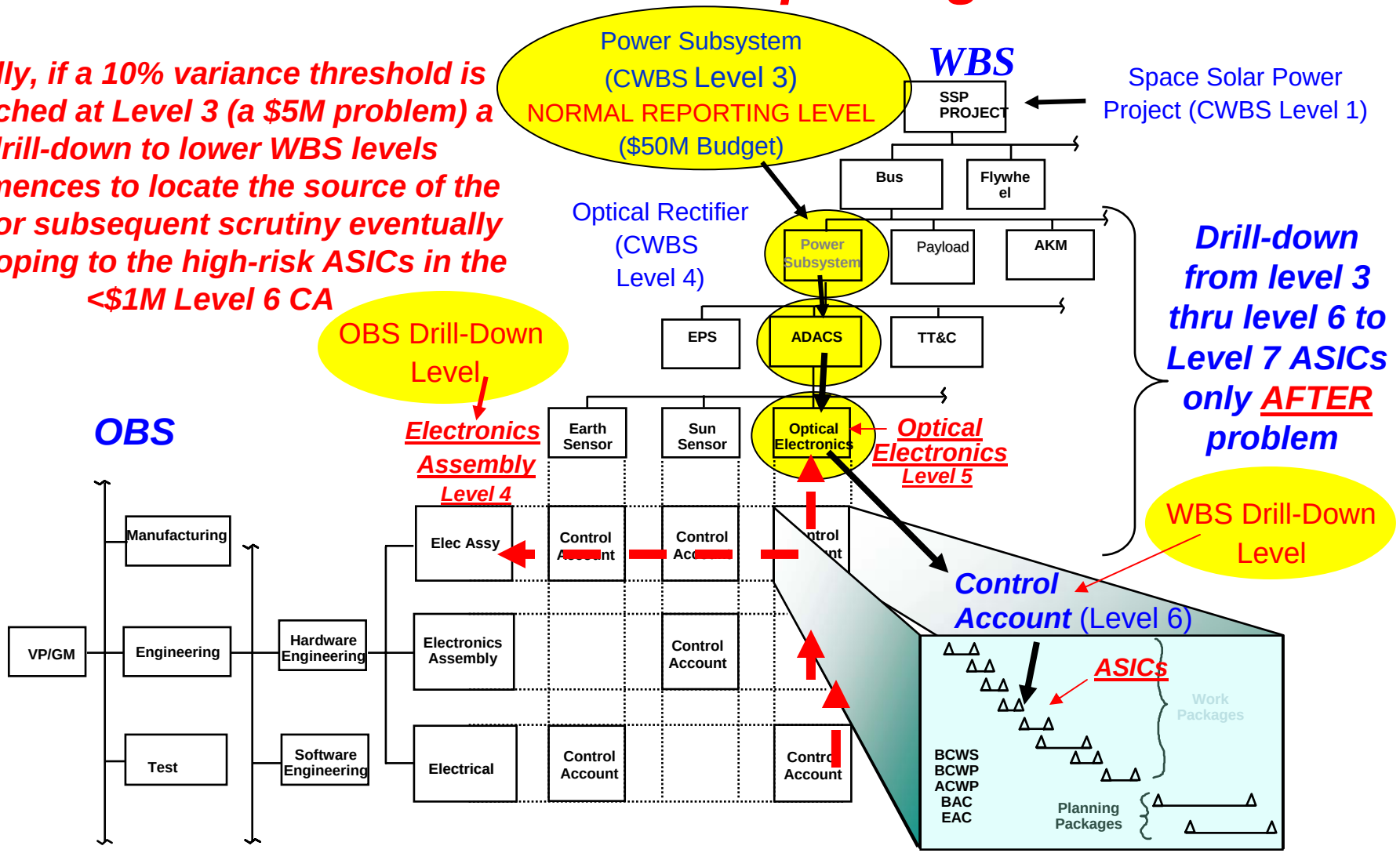
If WBS elements, other than those identified here, begin to experience variances exceeding 10% at one or two levels above the control account (source of risk) for two consecutive months in current month performance measurement, the contractor/performing organization will inform the Project Manager and a consensus reached on adding them to the group of high risk WBS elements identified for monthly cost performance reporting and analysis purposes.

All other WBS elements shall have earned value (BCWS, BCWP, ACWP) reported at level 3 of the WBS to satisfy observing and monitoring requirements

Traditional Level 3 Reporting

10% Variance Reporting

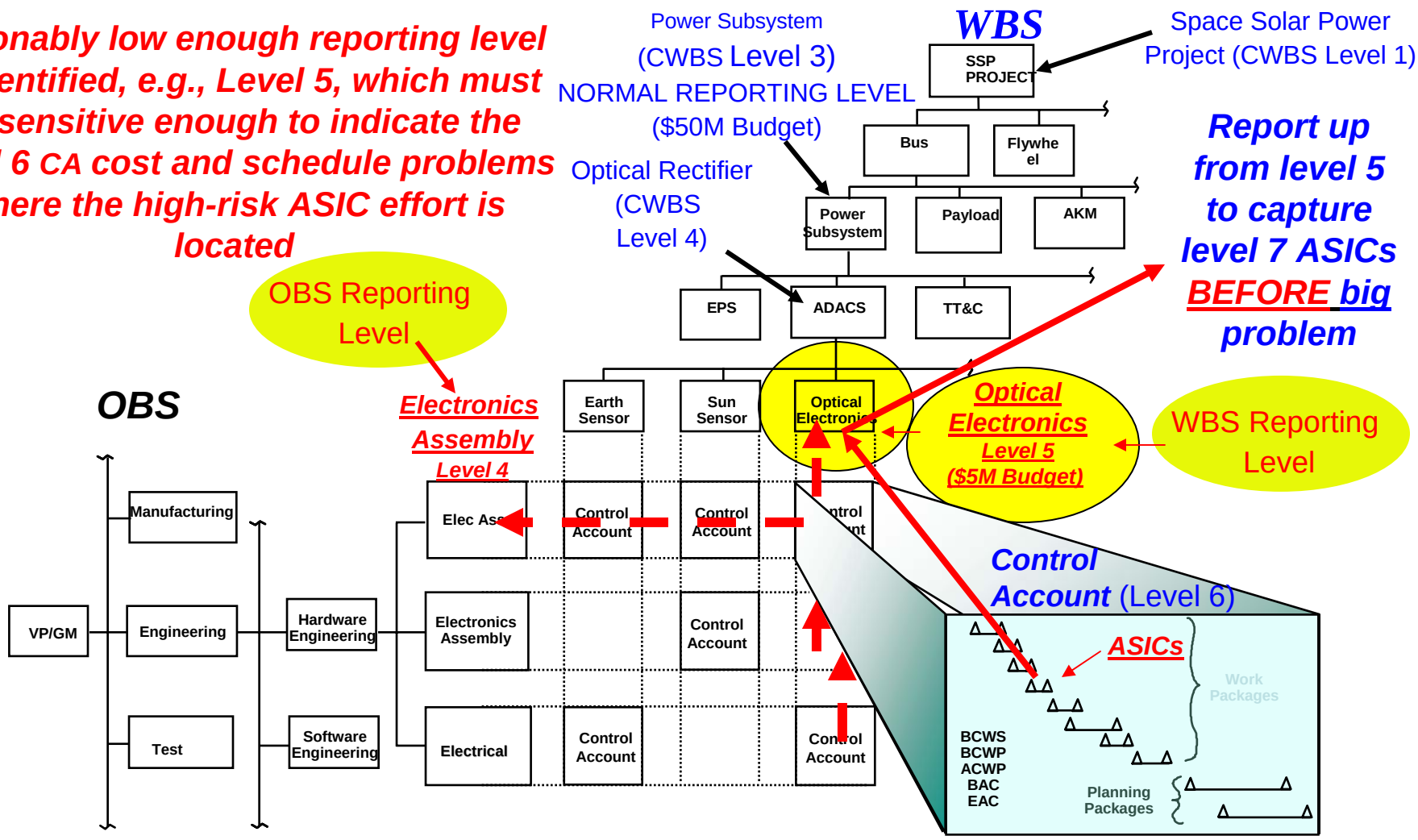
Normally, if a 10% variance threshold is breached at Level 3 (a $5M problem) a drill-down to lower WBS levels commences to locate the source of the risk for subsequent scrutiny eventually developing to the high-risk ASICs in the <$1M Level 6 CA



CCRM Med/High Risk Reporting

High-Risk No-Threshold Variance Reporting[3]

A reasonably low enough reporting level is identified, e.g., Level 5, which must be sensitive enough to indicate the Level 6 CA cost and schedule problems where the high-risk ASIC effort is located



[3]*Until risk is no longer a threat or is retired*

HIGH RISK CONTROL ACCOUNT

EV Techniques: 0/100, 50/50, Units Complete, % Complete, Milestones

CONTROL ACCT. TITLE: **Optical Frequency Demodulator**

CONTROL ACCOUNT MANAGER: Joe Hamaker

BUDGET: $10,000

TIER I MILESTONE — CA Start — CA COMP

WP#	WORK DESCRIPTION	EV METHOD		MONTH 1	MONTH 2	MONTH 3	MONTH 4	MONTH 5	MONTH 6	TOTAL BAC
			BCWS					1,500		1,500
1	**Procure Casing**	0/100								
			BCWP					1,500		
			BCWS			500	500			1,000
2	**Optical Freq Receiver**	50/50								
			BCWP			500		500		
			BCWS	600	600	600	600	600		3,000
3	**OPT-RF ASICs***	units complete								
			BCWP	600	600	-	1,200	600		
*High Risk: Req'd Monthly Reporting			**BCWS**		1,000	1,000	1,000			3,000
4	**DC Transformer**	milestone			1	2	3			
			BCWP		1,000	-	1,000	1,000		
			BCWS				500	500	500	1,500
5	**Integration**	% complete								
			BCWP				-	300	1,200	
TOTAL CONTROL ACCOUNT PLAN			**BCWS**	600	1,600	2,100	2,600	2,600	500	10,000
			BCWP	600	1,600	500	2,200	3,900	1,200	10,000
	Schedule Variance	month		0	0	-1,600	-400	1,300	700	
		cumulative		0	0	-1,600	-2,000	-700	0	
	Actual Costs			700	1,700	1,300	2,300	5,200	2,100	13,300
	Cost Variance	month		-100	-100	-800	-100	-1,300	-900	
		cumulative		-100	-200	-1,000	-1,100	-2,400	-3,300	

Cost Performance EVM Analysis

CLASSIFICATION *(When filled in)*

COST PERFORMANCE REPORT
FORMAT 1 - WORK BREAKDOWN STRUCTURE

DOLLARS IN _____

Form Approved
OMB No. 0704-0188

1. CONTRACTOR	2. CONTRACT		3. PROGRAM	4. REPORT PERIOD
a. NAME	a. NAME		a. NAME	a. FROM *(YYYYMMDD)*
b. LOCATION *(Address and ZIP Code)*	b. NUMBER			b. TO *(YYYYMMDD)*
	c. TYPE	d. SHARE RATIO	b. PHASE *(X one)* RDT&E ☐ PRODUCTION ☐	

5. CONTRACT DATA							
a. QUANTITY	b. NEGOTIATED COST	c. EST. COST AUTHORIZED UNPRICED WORK	d. TARGET PROFIT/ FEE	e. TARGET PRICE	f. ESTIMATED PRICE	g. CONTRACT CEILING	h. ESTIMATED CONTRACT CEILING

6. ESTIMATED COST AT COMPLETION				7. AUTHORIZED CONTRACTOR REPRESENTATIVE	
	MANAGEMENT ESTIMATE AT COMPLETION (1)	CONTRACT BUDGET BASE (2)	VARIANCE (3)	a. NAME *(Last, First, Middle Initial)*	b. TITLE
a. BEST CASE				c. SIGNATURE	d. DATE SIGNED *(YYYYMMDD)*
b. WORST CASE					
c. MOST LIKELY					

8. PERFORMANCE DATA

ITEM (1)	CURRENT PERIOD BUDGETED COST WORK SCHEDULED (2)	CURRENT PERIOD BUDGETED COST WORK PERFORMED (3)	CURRENT PERIOD ACTUAL COST WORK PERFORMED (4)	CURRENT PERIOD VARIANCE SCHEDULE (5)	CURRENT PERIOD VARIANCE COST (6)	CUMULATIVE TO DATE BUDGETED COST WORK SCHEDULED (7)	CUMULATIVE TO DATE BUDGETED COST WORK PERFORMED (8)	CUMULATIVE TO DATE ACTUAL COST WORK PERFORMED (9)	CUMULATIVE TO DATE VARIANCE SCHEDULE (10)	CUMULATIVE TO DATE VARIANCE COST (11)	REPROGRAMMING ADJUSTMENTS COST VARIANCE (12)	REPROGRAMMING ADJUSTMENTS BUDGET (13)	AT COMPLETION BUDGETED (14)	AT COMPLETION ESTIMATED (15)	AT COMPLETION VARIANCE (16)
a. WORK BREAKDOWN STRUCTURE ELEMENT															
b. COST OF MONEY															
c. GENERAL & ADMINISTRATIVE															
d. UNDISTRIBUTED BUDGET															
e. SUBTOTAL *(Performance Measurement Baseline)*															
f. MANAGEMENT RESERVE															
g. TOTAL															
9. RECONCILIATION TO CONTRACT BUDGET BASE															
a. VARIANCE ADJUSTMENT															
b. TOTAL CONTRACT VARIANCE															

Optical Electronics

Current Period
(BCWS, BCWP, ACWP)

Cum-to-Date
(BCWS, BCWP, ACWP)

DD FORM 2734/1, AUG 96 PREVIOUS EDITION MAY BE USED. LOCAL REPRODUCTION AUTHORIZED.

CLASSIFICATION *(When filled in)*

CCRM Cost-Risk Management

- CPR will deliver *key performance measurement* data on *medium and high risk WBS* elements monthly
- This will enable the project managers to *determine actions to take* to mitigate potential problems
- The *NASA project manager* works closely with the *in-house NASA control account managers (CAMs) and contractor CAMs* to determine what mitigation actions to take
- The *NASA project manager* works with both *in-house and contactor CAMs* to determine if *performance measurement can be dropped* on previously risky WBS elements due to risk retirement

Conclusion

- Focused on cost-risk identification, assessment, analysis and management
- CRM engineering has vital input value to cost estimating cost-risk
- CCRM cost-risk quantification has vital output value to CRM engineering
- Bottom-line:
  - CRM and CCRM are complementary disciplines