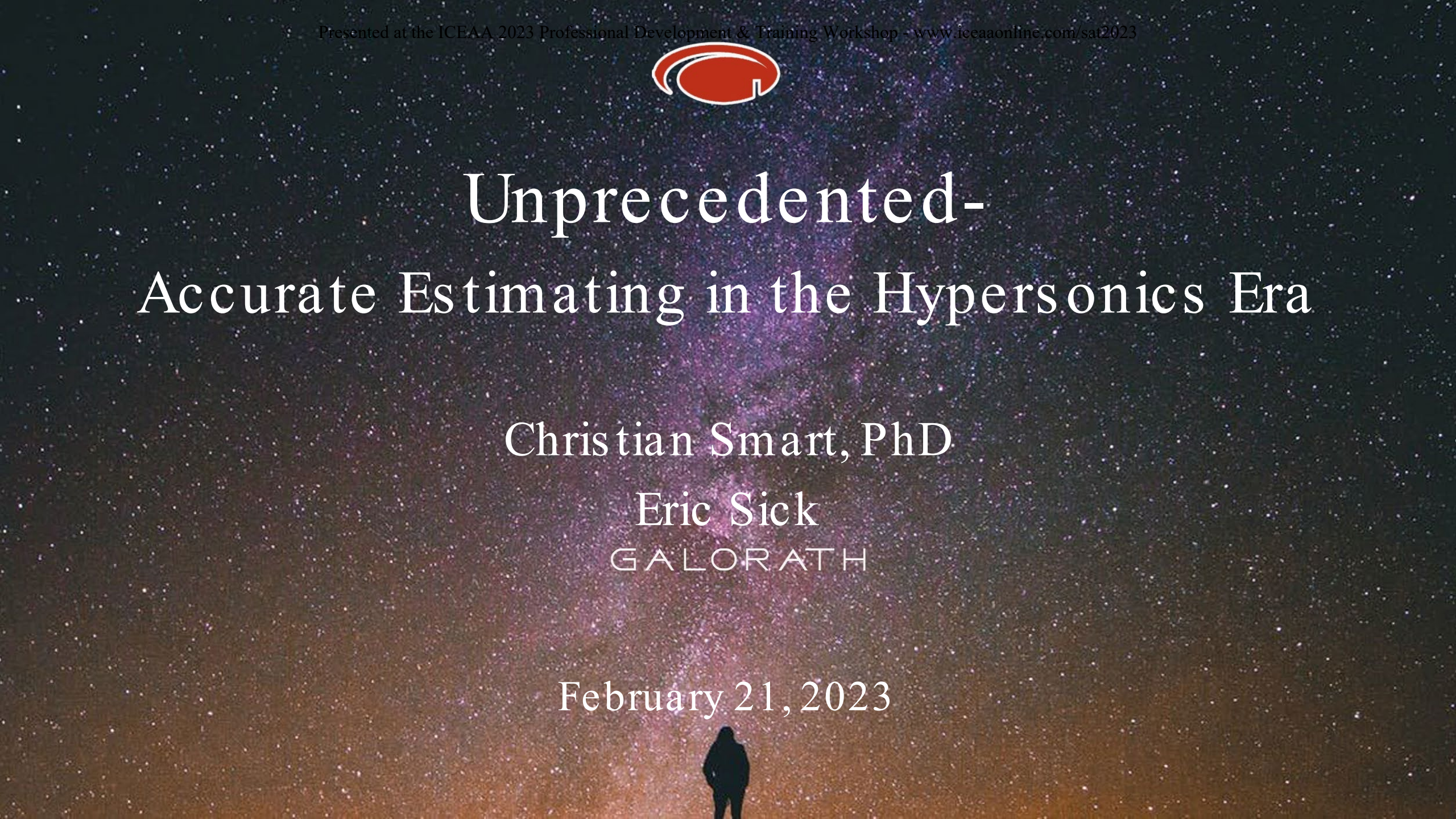


Unprecedented-

Accurate Estimating in the Hypersonics Era

Christian Smart, PhD

Eric Sick

GALORATH

February 21, 2023

GALORATH'S EXPERIENCE IN HYPERSONICS AND ADVANCED TECHNOLOGIES

EXPERIENCE ON MULTIPLE PROJECTS IN THE LAST FIVE YEARS

1

DARPA

Experimental Space Plane
Tactical Boost Glide
Advanced Full Range Engine
Hypersonic Airbreathing Weapon Concept

2

COMPARATIVE TECHNOLOGIES OFFICE

SCIFiRE

3

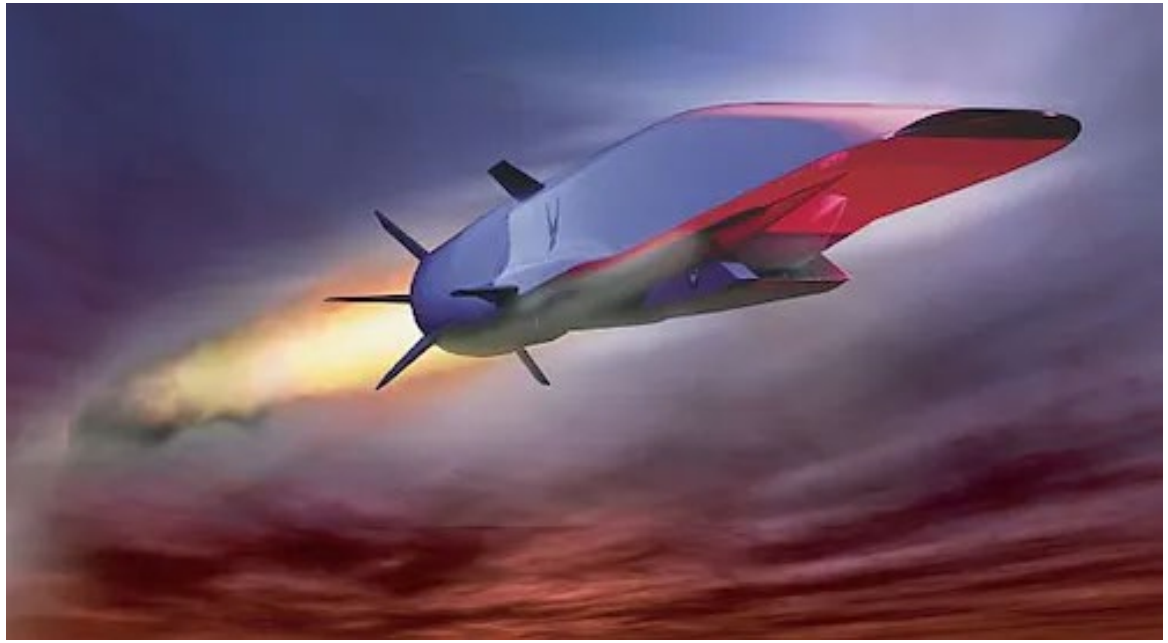
SPACE DEVELOPMENT AGENCY

Developed estimates for constellations of earth-orbiting satellites

4

GOVERNMENT AND COMMERICIAL

We have developed independent estimates for both OSD/MDA and Virgin Galactic



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COST ESTIMATING METHODOLOGIES

1

ANALOGY

Uses a similar historical project as a basis of estimate, with adjustments based on differences

2

PARAMETRIC

Based on multiple historical data points to develop cost estimating relationships

3

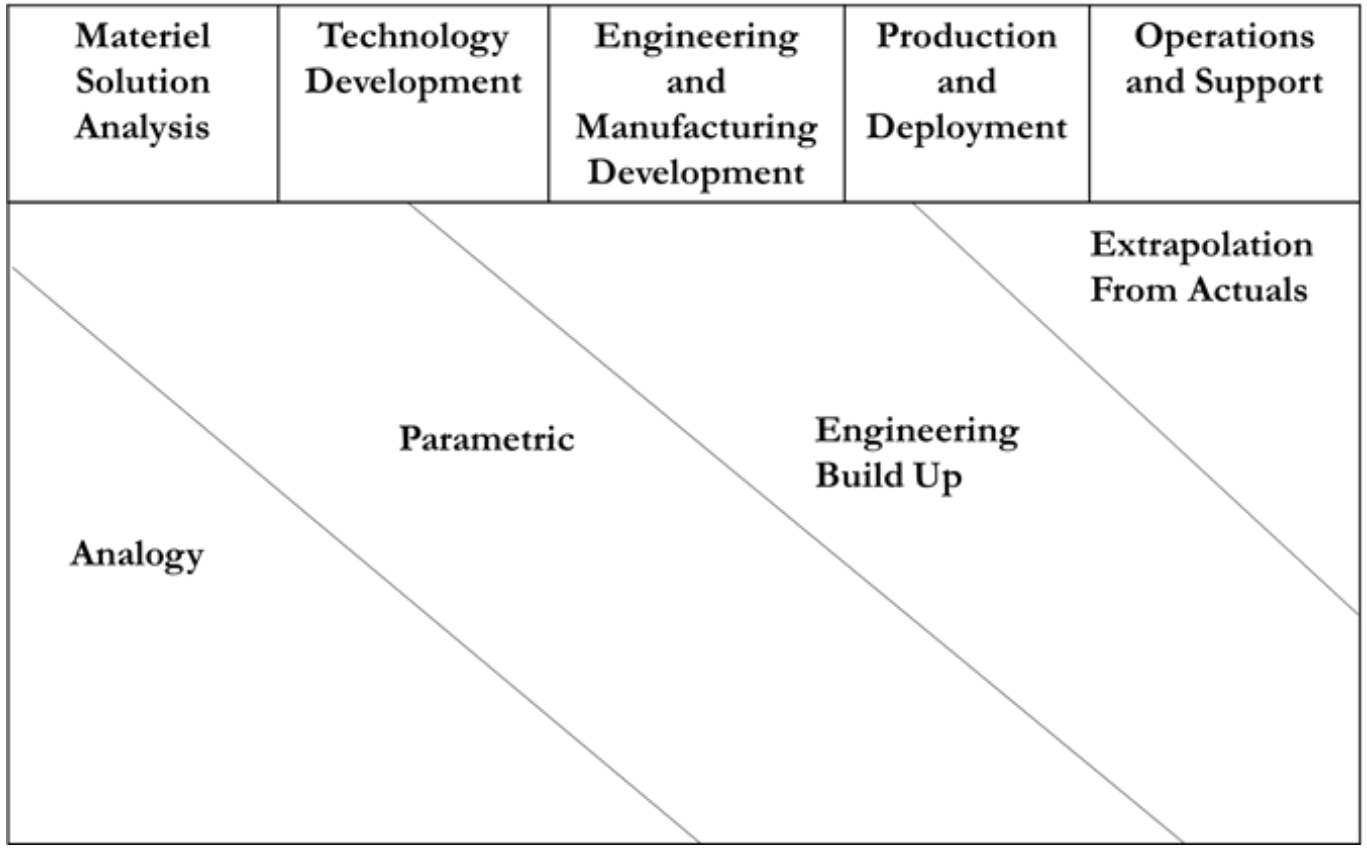
ENGINEERING BUILD-UP

Low-level Work Breakdown Structure, can involve detailed estimates of labor rates, time, and material costs

4

EXTRAPOLATION FROM ACTUALS

Uses recent historical data for an activity to forecast the near future



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ESTIMATING NOVEL TECHNOLOGIES

COPING WITH THE LAW OF SMALL NUMBERS

1

PARAMETRICS

Traditional parametric methods rely upon historical data

2

NOVEL TECHNOLOGIES

By their very definition, novel technologies have little if any direct historical precedent

3

CAN WE USE PARAMETRICS?

Can we still use parametrics for hypersonics when there is limited historical data?

4

YES WE CAN!

We discuss two existing parametric models for estimating hypersonic vehicles

"People's intuitions about random sampling appear to satisfy the law of small numbers, which asserts that the law of large numbers applies to small numbers as well." Daniel Kanheman and Amos Tversky

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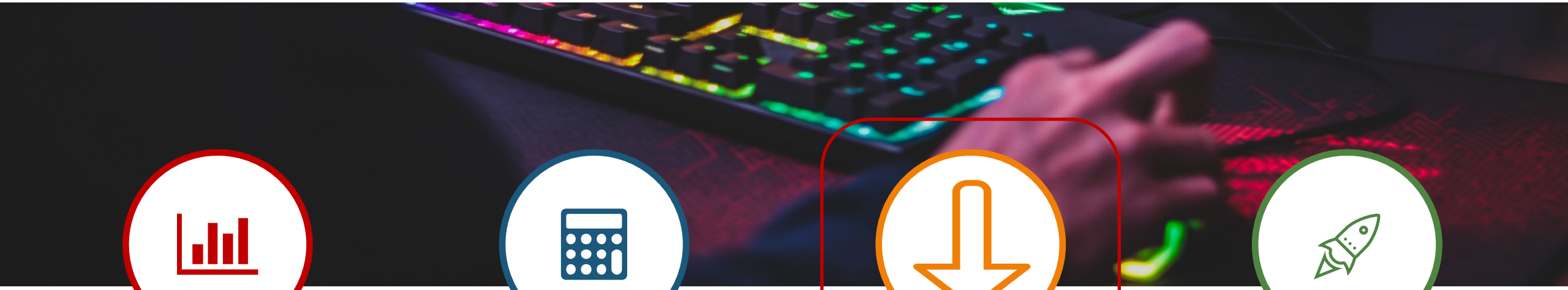
WHAT CAN BE DONE WITH LIMITED DATA?



COLLECT MORE DATA

WORK WITH OTHER GOV'T AGENCIES (E.G., AIR FORCE, COMMERCIAL COMPANIES)

CAN BE DIFFICULT TO DO

IMPUTE

USE IMPUTATION TO FILL IN MISSING DATA

NEED TO BE CAREFUL TO CONSERVE CORRELATION STRUCTURES

GO LOWER

ESTIMATE AT THE COMPONENT LEVEL INSTEAD OF THE SUBSYSTEM LEVEL

MORE NOISE

BAYES

USE TECHNIQUES DESIGNED TO ESTIMATE WITH LIMITED DATA

SUBJECTIVE

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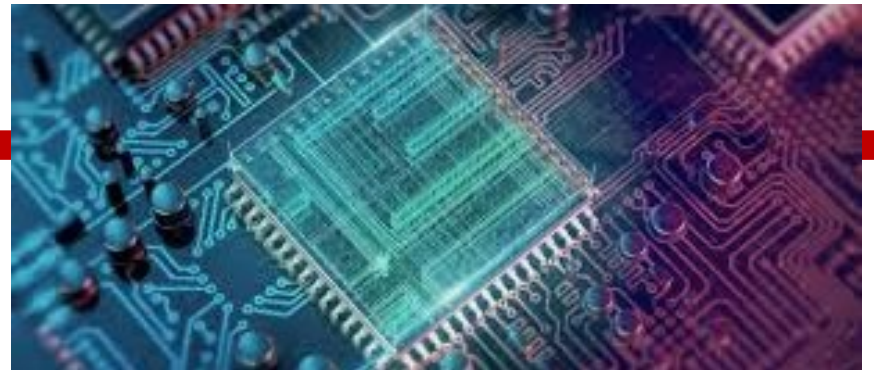
TWO APPROACHES

TOP-DOWN & BOTTOM-UP

Detailed component-level model based on thousands of data points



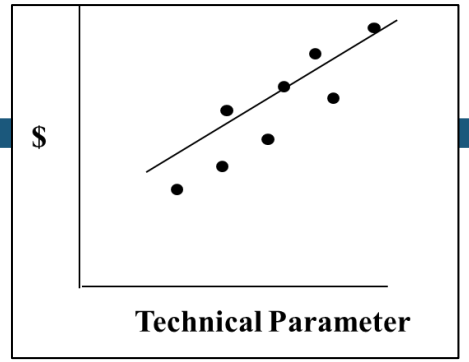
PRIMARY METHOD

If you break new technologies down to the component level, you find that many of these have components that have been used before

These models have inputs that can model the engineering and physics required for hypersonic flight

These models are ideal for working with engineers at the design level

System-level model based on twenty historical data points



CROSS-CHECK

NASA and other agencies have developed vehicles capable of Mach5+ velocities – there are meaningful trend lines between cost and weight for these systems

Provides a test of reasonableness

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Decomposition

1 System

Poor data availability
Very poor applicability

2 Vehicle

High data availability
limited applicability

3 Subsystem

Compromise between applicability and availability
Drivers more difficult to parse

4+ Assembly
Subassembly
Component

Optimal Work Breakdown Structure detail and available data volume, lower availability

WBS#	Level 1	Level 2	Level 3	Level 4	Level 5
1.0	Aircraft System				
1.1		Aircraft System, Integration, Assembly, Test and Checkout			
1.2		Air Vehicle			
1.2.1			Air Vehicle Integration, Assembly, Test and Checkout		
1.2.2			Air Frame		
1.2.2.1				Airframe Integration, Assembly, Test, and Checkout	
1.2.2.2				Fuselage	
1.2.2.3				Wing	
1.2.2.4				Empennage	
1.2.2.5				Nacelle	
1.2.2.6				Other Airframe Components 1…n (Specify)	
1.2.3			Propulsion		
1.2.4			Vehicle Subsystems		
1.2.4.1				Vehicle Subsystem Integration, Assembly, Test, and Checkout	
1.2.4.2				Flight Control Subsystem	
1.2.4.3				Auxiliary Power Subsystem	
1.2.4.4				Hydraulic Subsystem	
1.2.4.5				Electrical Subsystem	
1.2.4.6				Crew Station Subsystem	
1.2.4.7				Environmental Control Subsystem	
1.2.4.8				Fuel Subsystem	
1.2.4.9				Landing Gear	
1.2.4.10				Rotor Group	
1.2.4.11				Drive Group	
1.2.4.12				Vehicle Subsystem Software Release 1...n (Specify)	
1.2.4.13				Other Subsystems 1...n (Specify)	
1.2.5			Avionics		
1.2.5.1				Avionics Integration, Assembly, Test, and Checkout	
1.2.5.2				Communication/Identification	
1.2.5.3				Navigation/Guidance	
1.2.5.4				Mission Computer/Processing	
1.2.5.5				Fire Control	
1.2.5.6				Data Display and Controls	
1.2.5.7				Survivability	
1.2.5.8				Reconnaissance	
1.2.5.9				Electronic Warfare	
1.2.5.10				Automatic Flight Control	
1.2.5.11				Health Monitoring System	
1.2.5.12				Stores Management	
1.2.5.13				Avionics Software Release 1...n (Specify)	
1.2.5.14				Other Avionics Subsystems 1...n (Specify)	
1.2.6			Armament/Weapons Delivery		
1.2.7			Auxiliary Equipment		
1.2.8			Furnishings and Equipment		
1.2.9			Air Vehicle Software Release 1...n (Specify)		
1.2.10			Other Air Vehicle 1...n (Specify)		

TOTAL COST OF OWNERSHIP

DEVELOPMENT

- Engineering design
- Prototype fabrication
- Engineering test, system integration &test
- Systems engineering, program management
- Engineering, management, support data
- Peculiar support equipment and tooling

PRODUCTION

- Total, Average Unit, and First Unit Costs
- Material, Fabrication, Integration & Assembly
- Production Support, Sustaining Engineer
- Program Management, and Tooling Maintenance

LOGISTICS PARAMETERS

- MTBF
- Op hours to maturity
- MTTR
- Volatility factor

OPERATING & SUPPORT

- Operator Labor; Maintenance/Support Labor
- Parts/Consumables/Spares
- Maintenance Training; Inventory Management; Data Management; Shipping

THANK YOU

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