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SAND2015-0031PE
R&A xxxxxx

Jerrod Peterson

14 Jan 2015

PhD defense, Stanford University mechanical engineering

Diffusion of Designerly FEA

(finite element analysis)

FEA is powerful but faces negative perceptions in the product design community.
What are the real issues underlying this resistance?
How does *confidence* play a role in a design team's utilization of FEA?

Introduction

FINITE ELEMENT ANALYSIS

- Simulation technology
- Developed in 1950's for aerospace structural mechanics
- Widespread use by 1980's
- Recognized potential to impact design

Few tools have shown such great power and promise for the future of product design as finite element analysis (FEA). The ability to simulate the performance of a part or system prior to building a physical prototype is only beginning to filter into the world of design engineering.

Adams and Askenazi (1999, p. xxix)

RESEARCH MOTIVATION

- Sandia management pushes for wider use of FEA in product development
- FEA resides in the domain of "science"
- Resistance to FEA in product design community
- Existing models of FEA in design process do not address the issue of *technology diffusion*

Presentation outline

1. BACKGROUND

- Sandia context assessment
- Designerly FEA

2. RESEARCH METHODOLOGY

- Intervention structure
- Research questions
- Data collection
- Theory-building analysis

3. CASE STUDIES

- Application for case studies
- Case 1 design, FEA, & testing
- Case 2 design, FEA, & testing

4. RESULTS & CONCLUSION

- Findings
- Confidence model, parts 1 & 2
- Recommendations to Sandia
- Conclusion

Sandia context assessment

Online FEA survey

- Views and past experiences
- Submitted to ~160 Sandians
  - Jan. 2012 and Jan. 2014
  - CAS-pre: 67 respondents
  - CAS-post: 55 respondents

COST category	No.	%
FEA can reduce cost	11	47.8
Dollar cost too high	12	52.2
Total	**23**	**100.0**

Contention surrounding FEA in product development community.

Percentages of *comment volume* in each category.

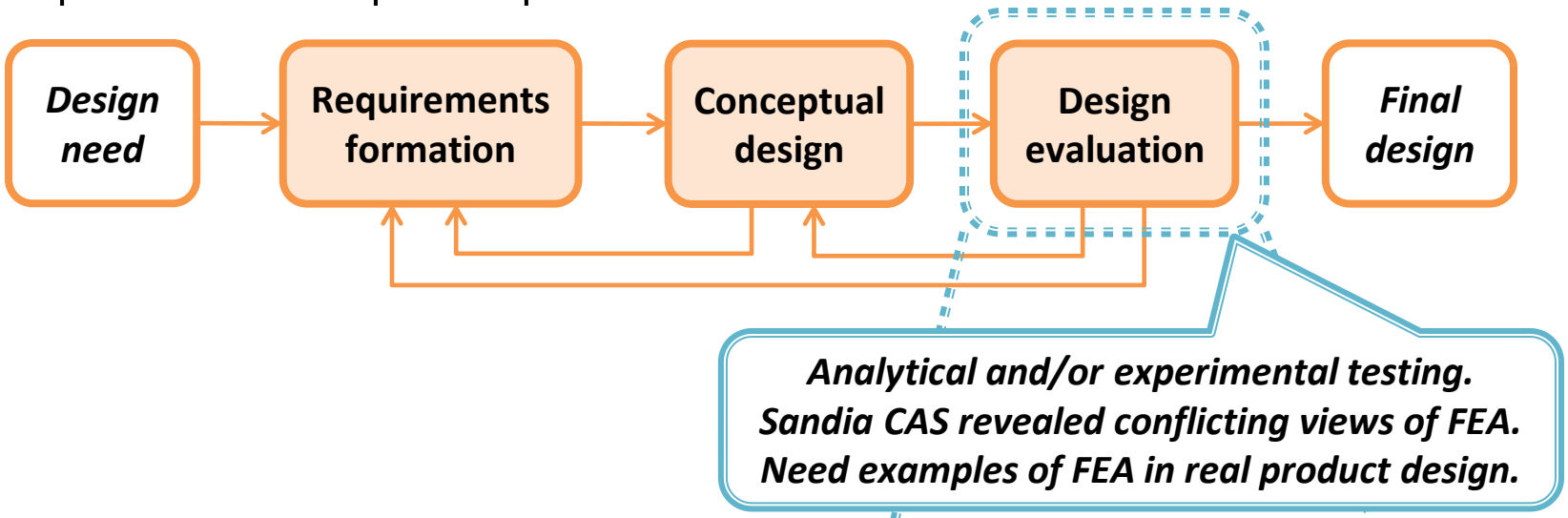
TIME category	No.	%
Identify issues early, guide design	34	62.3
FEA typically keeps pace with design	13	
FEA can save time	9	
FEA typically leads design	5	
FEA typically lags design	21	37.7
FEA takes too long	16	
Total	**98**	**100.0**

TESTING category	No.	%
Diagnose test failures	14	53.1
Reduce testing, design-test iterations	10	
Complements experimental testing	10	
Guides design of experiments	9	
Required for model/results validation	38	46.9
Total	**81**	**100.0**

* CAS = Context Assessment Survey. Example results from CAS-pre data.

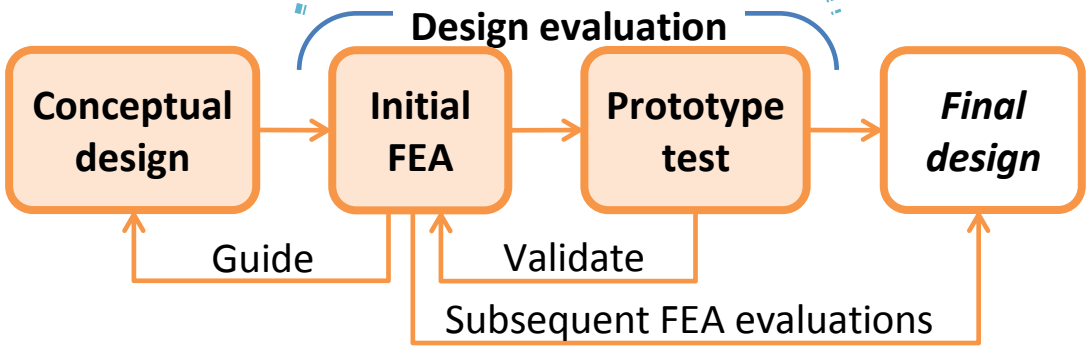
Designerly FEA

Typical product development process at Sandia.



Designerly FEA

- Simplified FEA models
- Designer-friendly software
- Analyst in design team
- Relative comparisons
- 1st prototype test validates



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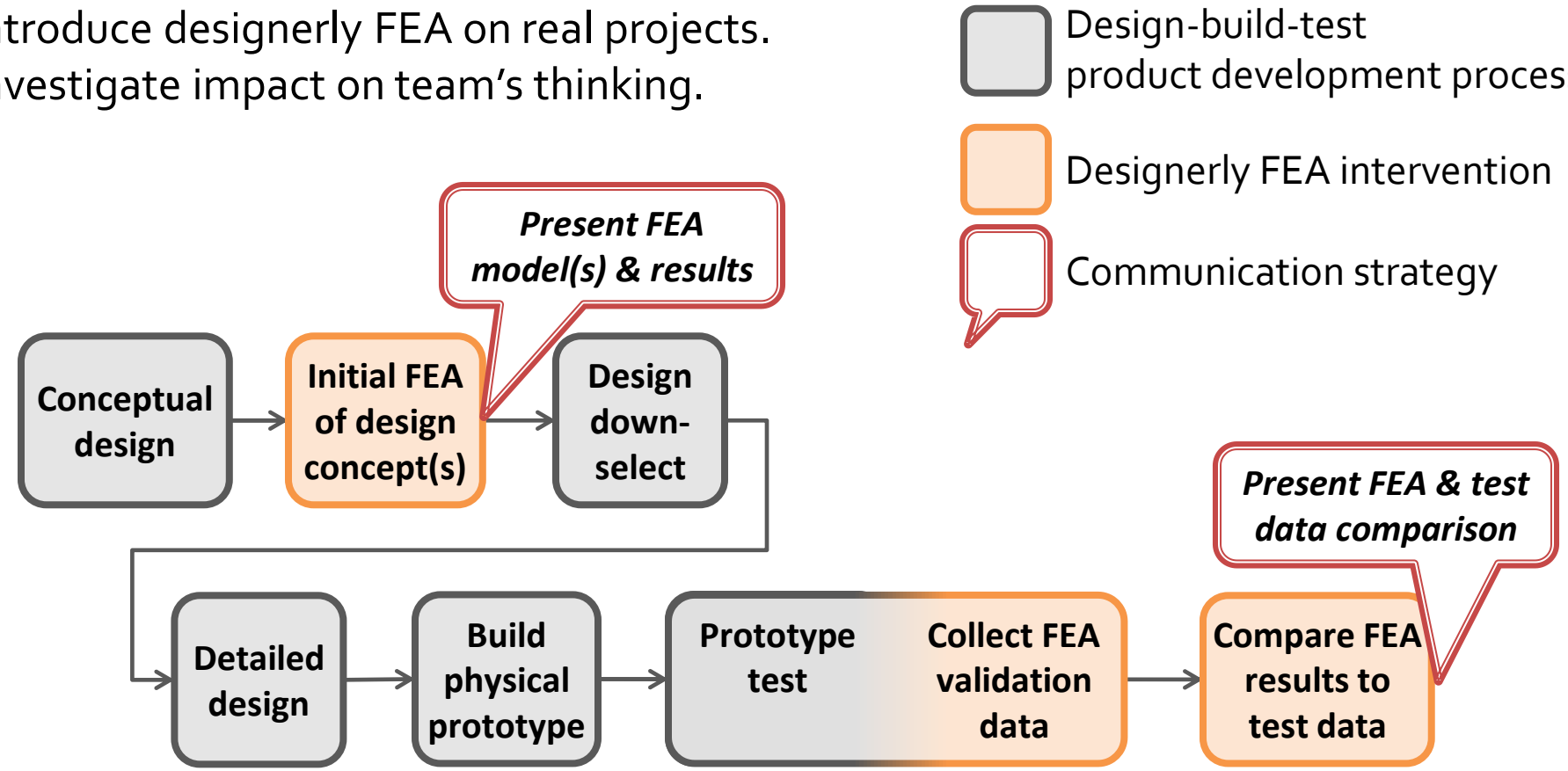
Intervention structure

Introduce designerly FEA on real projects.
Investigate impact on team's thinking.



Research questions

RQ1. What are the product development teams' perceptions of FEA?

RQ2. How does designerly FEA impact the teams' design thinking?

RQ3. How do the teams' views change on common barriers to adoption?

RQ4. How likely are the product development teams to carry the use of FEA forward?

Perceptions

Perceptions count. The individuals' perceptions of the attributes of an innovation, not the attributes as classified objectively by experts or change agents, affect its rate of adoption.

Rogers (2003, p. 223)

Reflective research

A mechanical engineer may see himself as a technical problem solver, treating his relations with his clients as an unavoidable but essentially nonprofessional activity. Or … he may frame his tasks in such a way that a larger social context moves to the foreground and technical problem solving becomes a piece of the larger social puzzle.

Schön (1983, p. 274-275)

Data collection

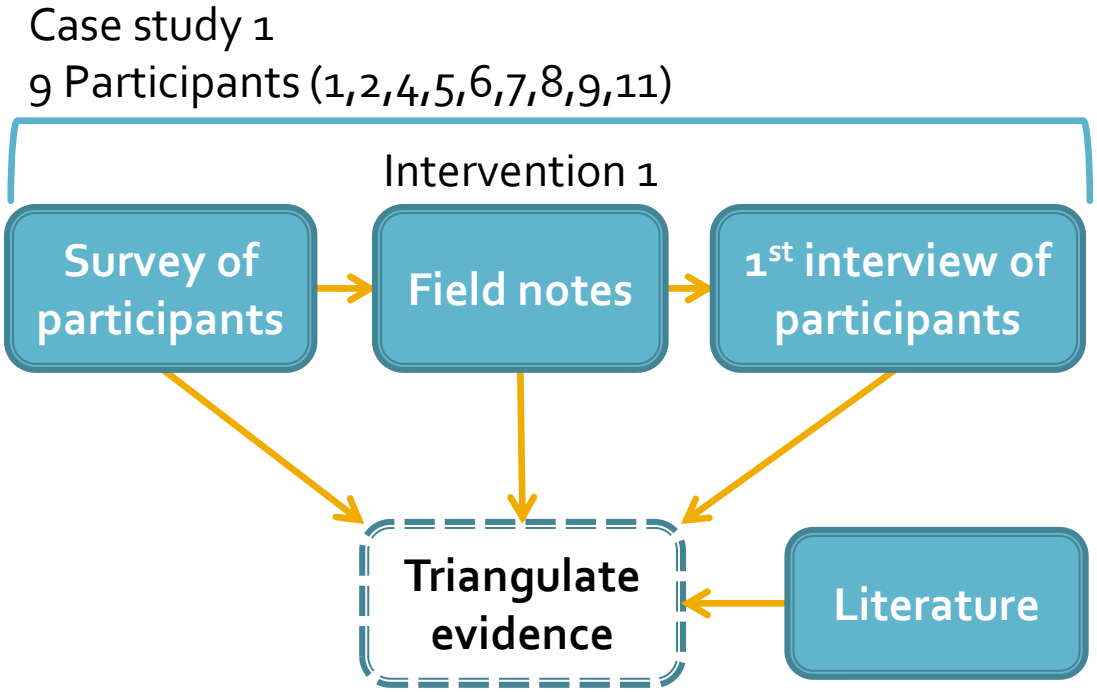
Case study 1
9 Participants (1,2,4,5,6,7,8,9,11)

* Participants are design team members.

Case study 2
7 Participants
(1,4,7,8,11,12,13)

- Multiple case design
- Participants are embedded units of analysis
- Mixed-method data collection
- Follows emergent themes (Corbin & Strauss, 1990)
- Longitudinal

Theory-building analysis



Eisenhardt (1989)
Yin (2009)

- Analysis of case 1
- Analysis of case 2
- Cross-case analysis
  - Literal replication
  - Theoretical replication
- Synthesis
  - Relate to extant literature

- Case study teams representative of Sandia
  - Technical backgrounds
  - Length of time at Sandia
  - Present role(s)
  - FEA exposure

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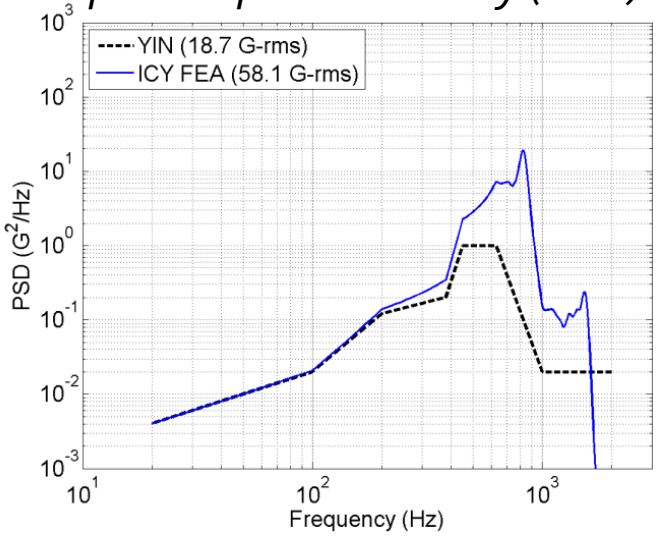
Application for case studies

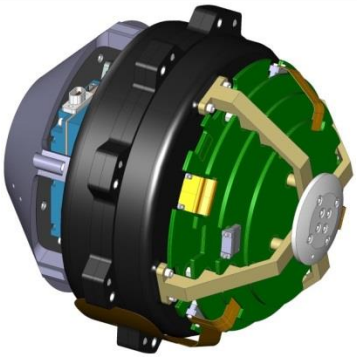
Dynamic response of electronics packaging

- Non-intuitive area of design
- Requires only coarse design detail
- Leverage routine product testing

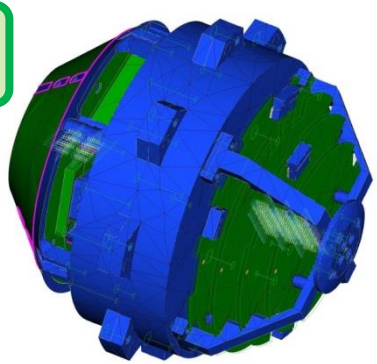
Strong potential for designerly FEA.

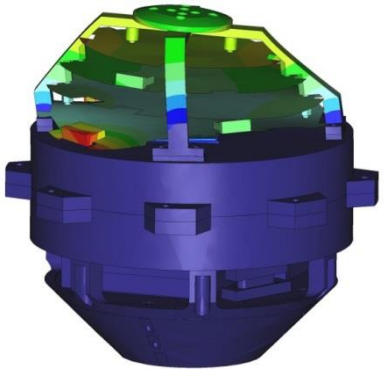
Random vibration power spectral density (PSD)



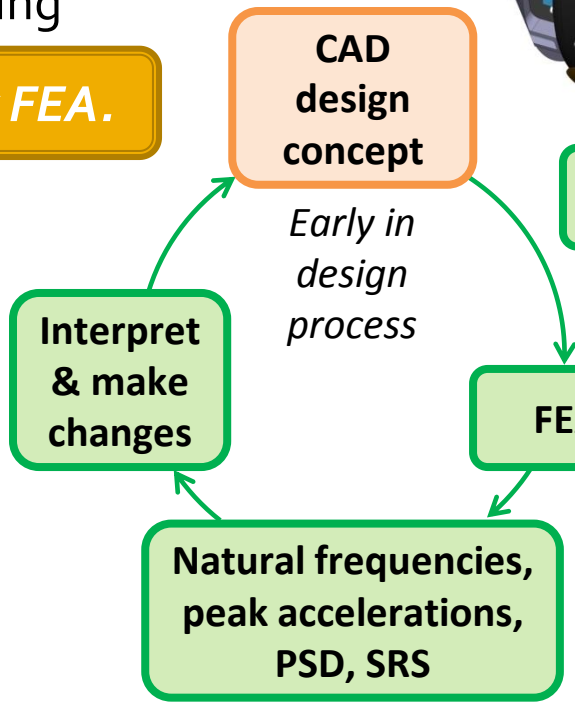


Mesh





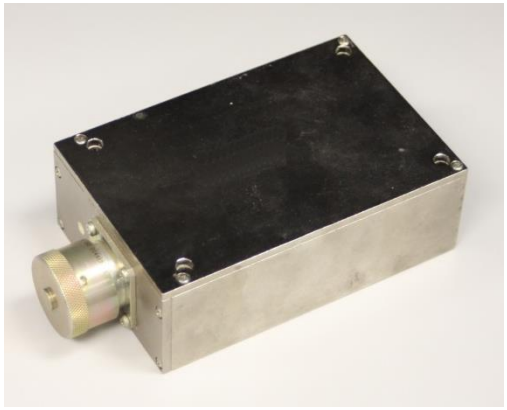
Modal analysis



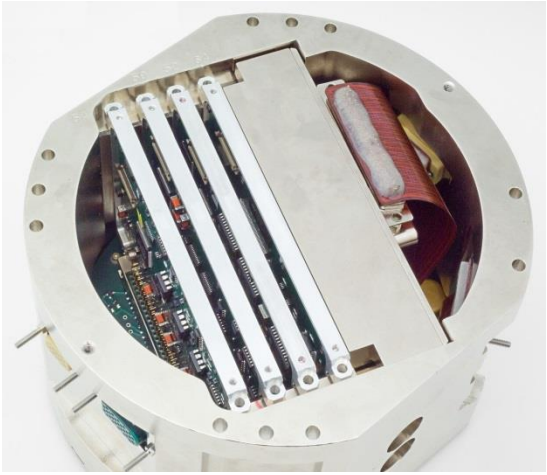
Case 1 design, FEA, & testing

- Install electronics module into existing package
- Driving design needs:
  - Fit in required volume
  - Prevent severe resonances at module and plug-in circuit board cards
- Goal: 9 months from concept to tested, fully-functional prototype
- 3 concepts explored

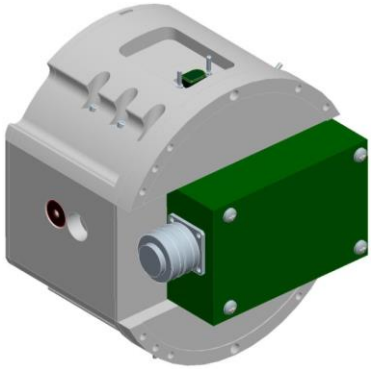
Electronics module



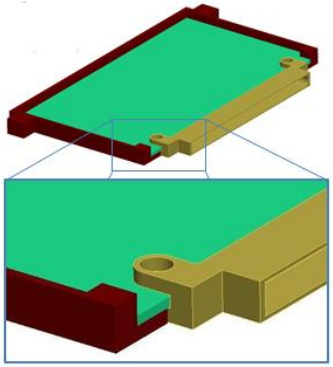
Existing package



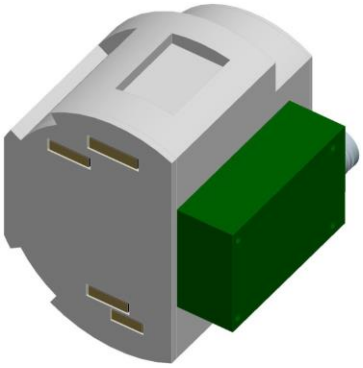
1. Baseline



2. Baseline w/ thinner cards

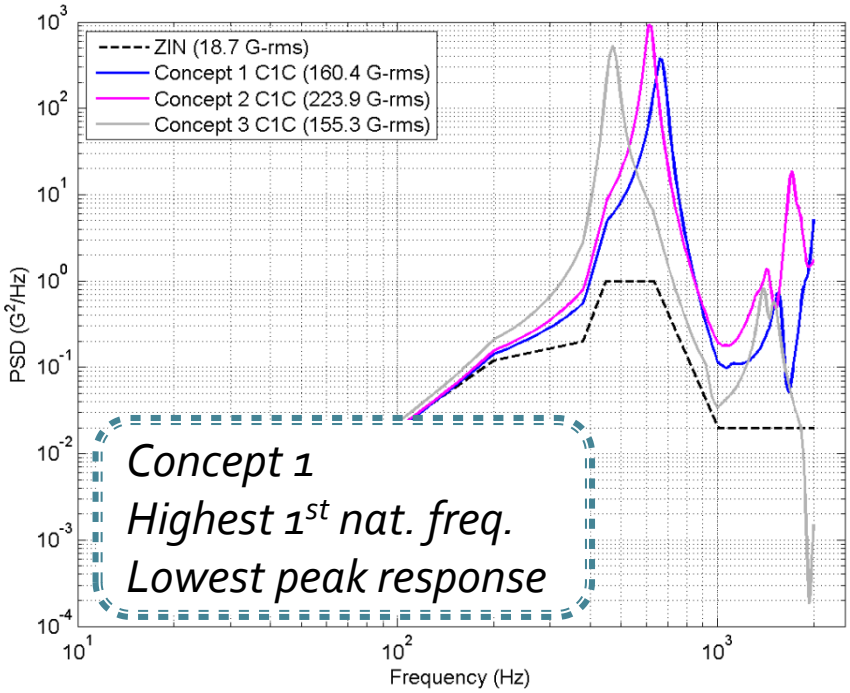


3. New aspect ratio



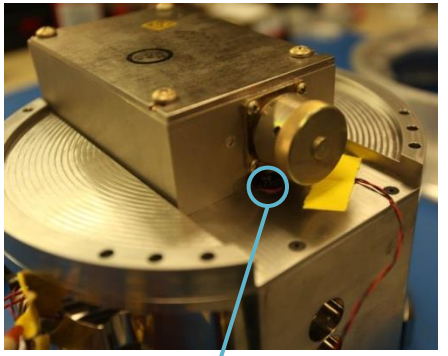
Case 1 design, FEA, & testing

Example comparison of design options.
Vibration at center of plug-in cards.

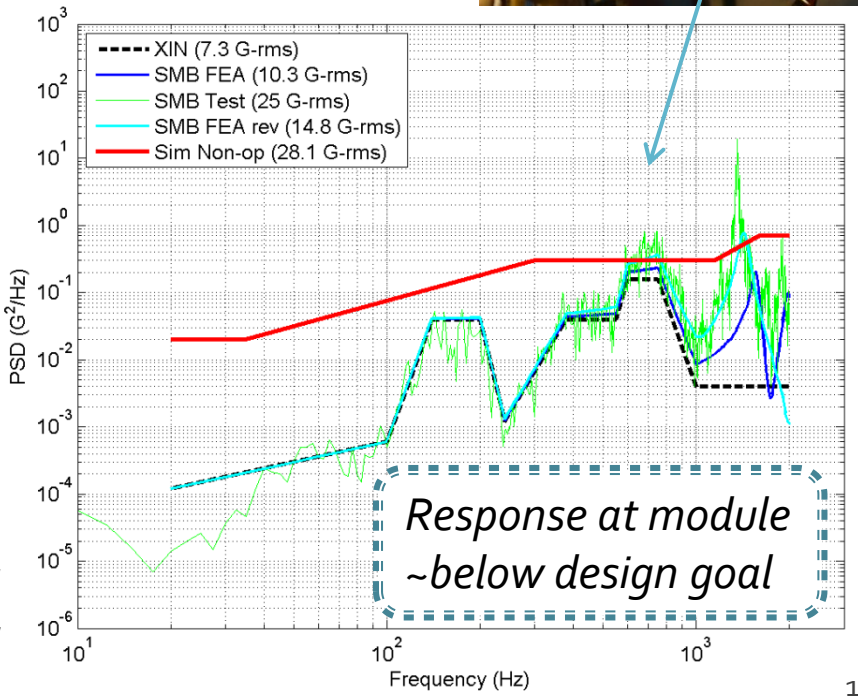


Plug-in card

Complete prototype

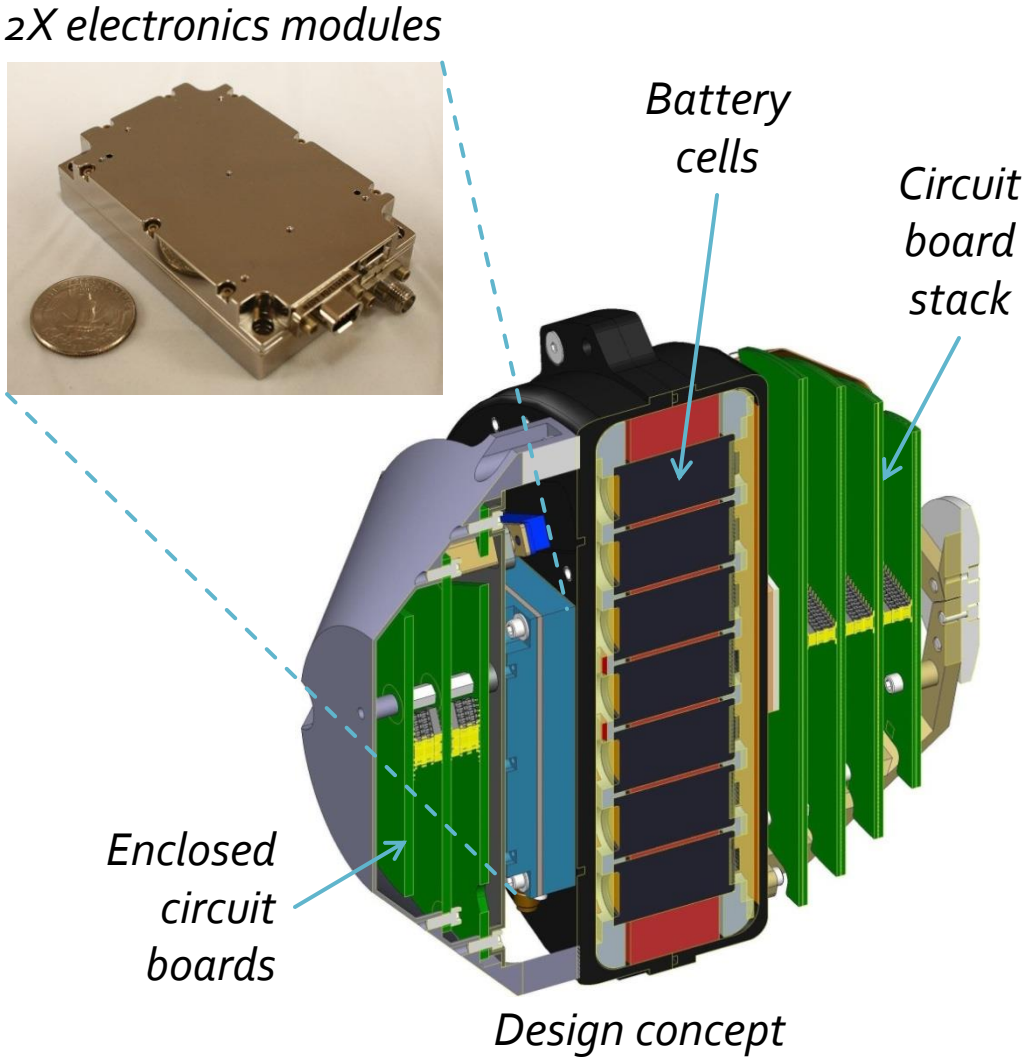


Example comparison to test data.
Vibration measured at module.



Case 2 design, FEA, & testing

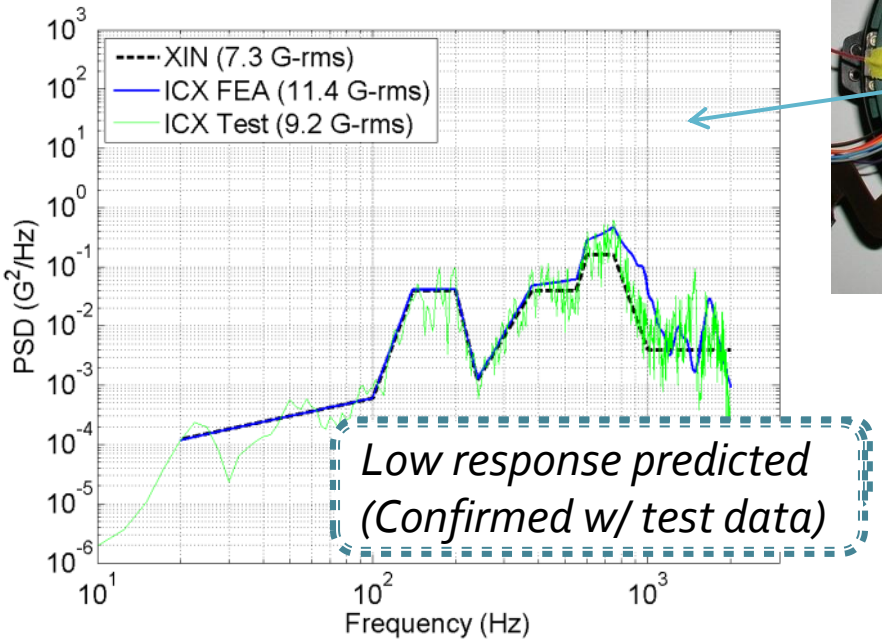
- Design <u>new</u>, self-powered electronics package
- Driving design needs:
  - Aggressive volume & weight requirements
  - Incorporate 2x electronics modules
  - Sufficient circuit board area
  - Prevent severe structural resonances in structural members & circuit boards
- Goal: 18 months from concept to tested, partially-functional prototype
- 1 concept explored



Design concept

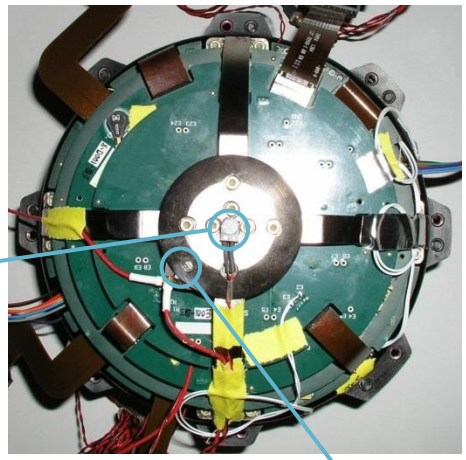
Case 2 design, FEA, & testing

Example results.
Vibration of circuit board stack, normal direction.

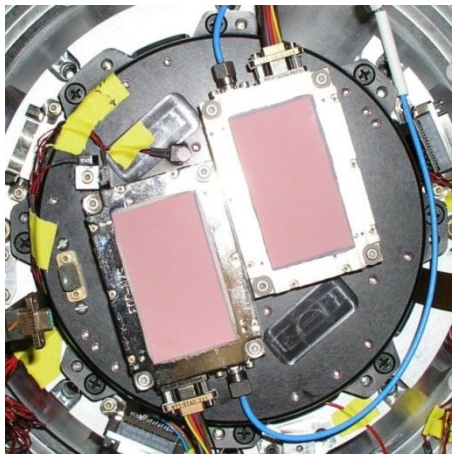


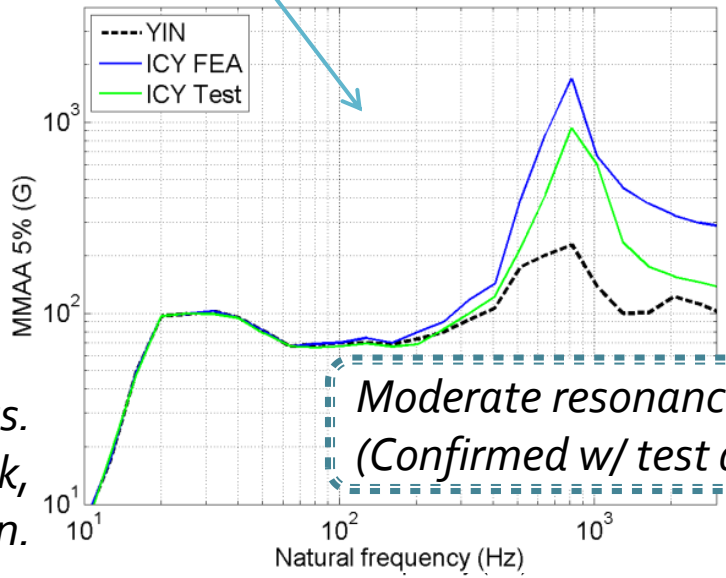
Low response predicted (Confirmed w/ test data)

Complete prototype



Modules & battery





Moderate resonance predicted (Confirmed w/ test data)

Example results.
Shock response of circuit board stack, lateral direction.

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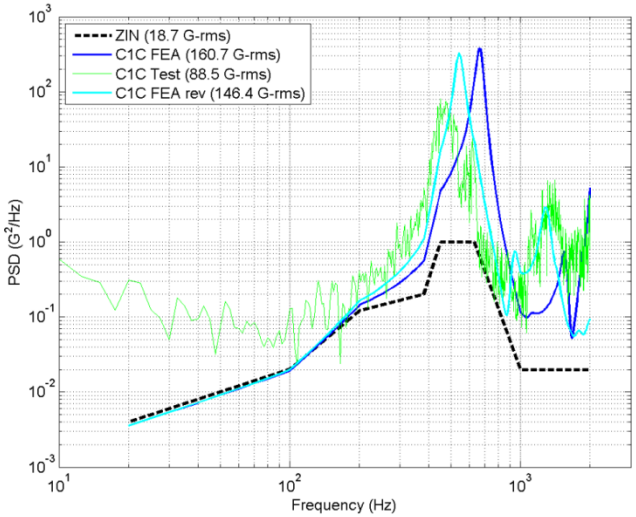
Findings: RQ1

What are the product development teams' perceptions of FEA?

Participants did not have <u>confidence in FEA</u> a priori. Confidence in FEA had to be earned.

- Direct comparison of FEA results to test data
- Confidence in the person performing the FEA



Initially, I was just very much in my electrical engineering world, and I didn't use FEA, and so … I just didn't have confidence in it.

Participant 5, end of case study 1

He built a lot of confidence in me by correlating his results with the real world results.

Participant 6, end of case study 1

I think my confidence in [FEA] is based on the person who is doing the FEA analysis, not the analysis itself.

Participant 12, end of case study 2

Case 1.
Vibration at center of plug-in cards.

Findings: RQ1

What are the product development teams' perceptions of FEA?

Previous encounters with FEA strongly influenced their perceptions and expectations in the case studies.

- Typically one defining previous encounter with FEA
- Either a positive or negative experience
- Noted by Adams and Askenazi (1999, p. 21)

  Typically, most preconceptions are based on some defining experience with the technology.

I was involved with [FEA] … on a project many years ago … where I saw … how much of a benefit [FEA] could be to a program. And I'm hoping … we'll be able to do that same type of thing.

Participant 1, beginning of case study 2

Other times … I observed the challenges where some of the funding … was coming from being very research-focused, … where the application was somebody who wanted to know, is their part going to break.

Participant 9, end of case study 1

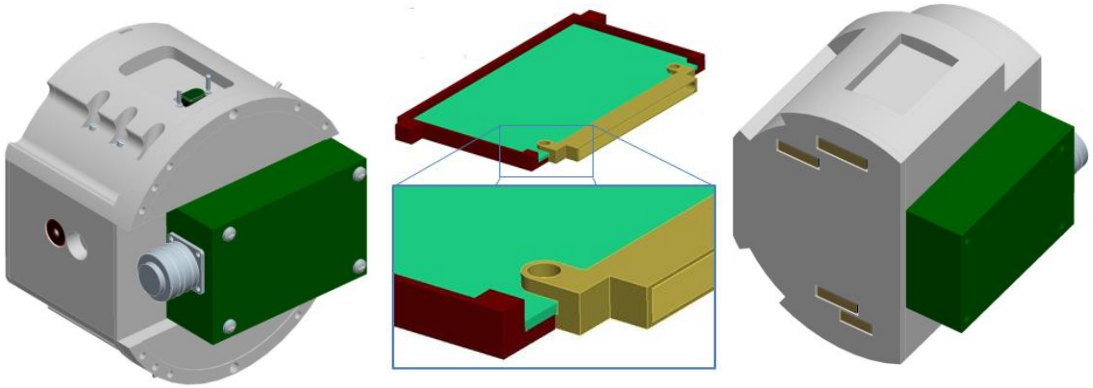
Underscores importance of providing positive experiences and avoiding negative ones.

Findings: RQ2

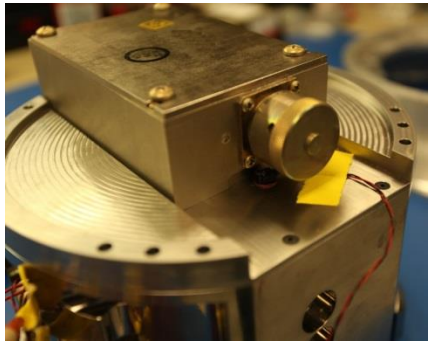
How does designerly FEA impact the teams' design thinking?

Participants primarily viewed FEA as a means to obtain <u>design confidence</u> (case 1).

- Design option down-select



- Assessing need for re-test after design changes that may nullify testing



From my vantage point, [the use of FEA] was all about gaining confidence. … We need to come up with an idea … in a very short period of time, and we have to be confident that it's going to work.

Participant 8, end of case study 1

We had really good confidence in being able to say, okay, we chose the best location [for the electronics module] and we have confirmation from a proven FEA analysis technique.

Participant 5, end of case study 1

Findings: RQ2

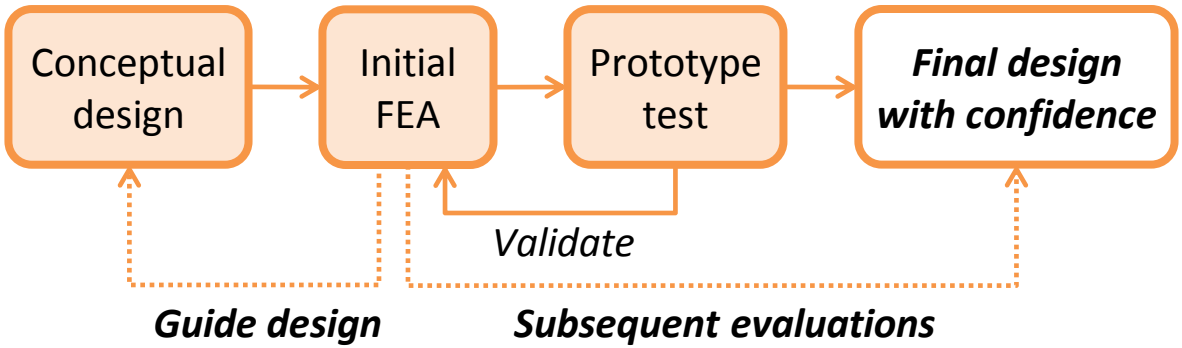
How does designerly FEA impact the teams' design thinking?

Participants expected to see tangible, direct evidence of FEA impacting product design and design decisions (case 2).

- In case 2, impact of FEA during conceptual design was limited

So far, I think we have a good base, but we haven't actually done anything with it, other than to show that, oh, hey, our model matches our test results. … But hopefully in the future … we have design changes that can be evaluated using the model that we have.

Participant 7, end of case study 2



Findings: RQ2

How does designerly FEA impact the teams' design thinking?

Participants leveraged various sources of design knowledge to build confidence, but <u>FEA served a supporting role</u>.

- Design similarity (case 1)

Much everyday design work entails the use of precedents or previous exemplars—not because of laziness by the designer but because the exemplars actually contain knowledge of what the product should be. Cross (2007, p. 126)

- Prototype test results (cases 1 and 2)

There was kind of like one or two or three different paths we could have gone down, and FEA sort of confirmed that the path we were going down was okay. I don't think it necessarily led us down that path. … But … it made us more confident that that was a good path to go down.

Participant 7, end of case study 1

[FEA] only confirmed [design confidence] after I looked at the test data. That's where I saw the comparison between the FEA results and the test, and that's where I felt very confident with the design.

Participant 12, end of case study 2

Findings: RQ3

How do the teams' views change on common barriers to adoption?

The time required to use FEA was a difficult barrier to overcome in the participants' thinking.

- Hesitant to translate positive experiences into general beliefs
- Focused on long FEA run times in Case 2

CPU time	Case 1 per concept	Case 2
Modal	2 hr	5 hr
Vibration	17 hr	45 hr
Shock	23 hr	557 hr
Total	**42 hr**	**607 hr**

I think it's worth the time, but it's hard to get that time when you're on a fast-paced project.
Participant 4, end of case study 1

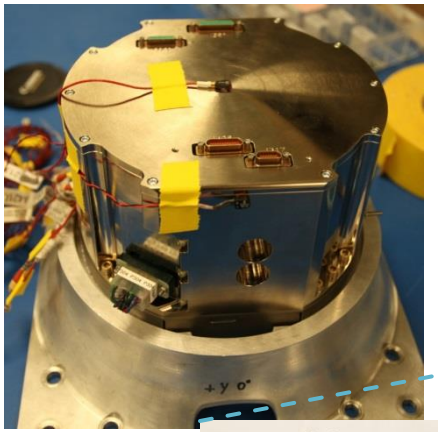
If these could run in 40 minutes, you know, instead of 40 hours, that's something which we would do much, much more often. But, it does take some time, so it's done less.
Participant 7, end of case study 2

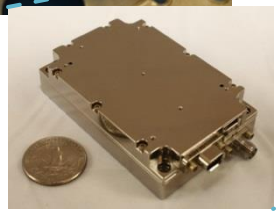
One version of his model seemed to be fairly reasonable, … but one aspect was insanely long … something like 600 hours. So, that is completely unreasonable … to be impactful.
Participant 11, end of case study 2

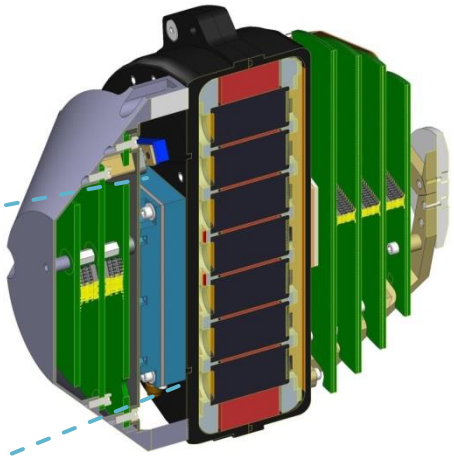
Findings: RQ4

How likely are they to carry the use of FEA forward?

Multiple participants <u>conceived of their own applications</u> for FEA over the course of the case studies.







- Sub-component failure levels
- Assessing need for re-test
- Sub-component requirements
- Thermal FEA modeling
- Guiding design changes

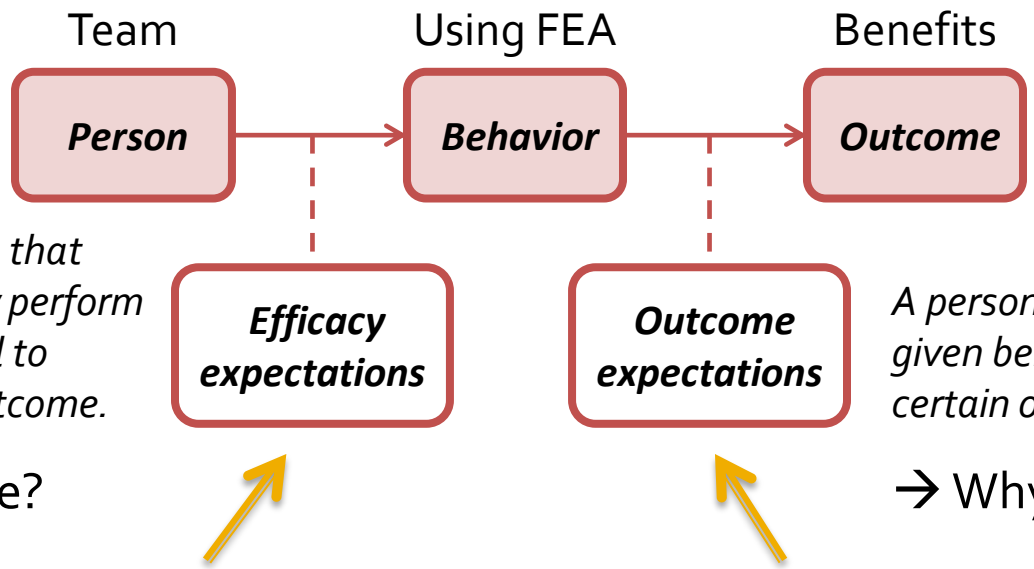
Strongest evidence of 'adoption' of FEA into their design thinking.

Potential adopters are on many occasions active participants in the adoption and diffusion process, struggling to give meaning to the new idea as the innovation is applied to their local context.

(Rogers, 2003, p. 187-188)

Efficacy & outcome expectations

Bandura (1977):



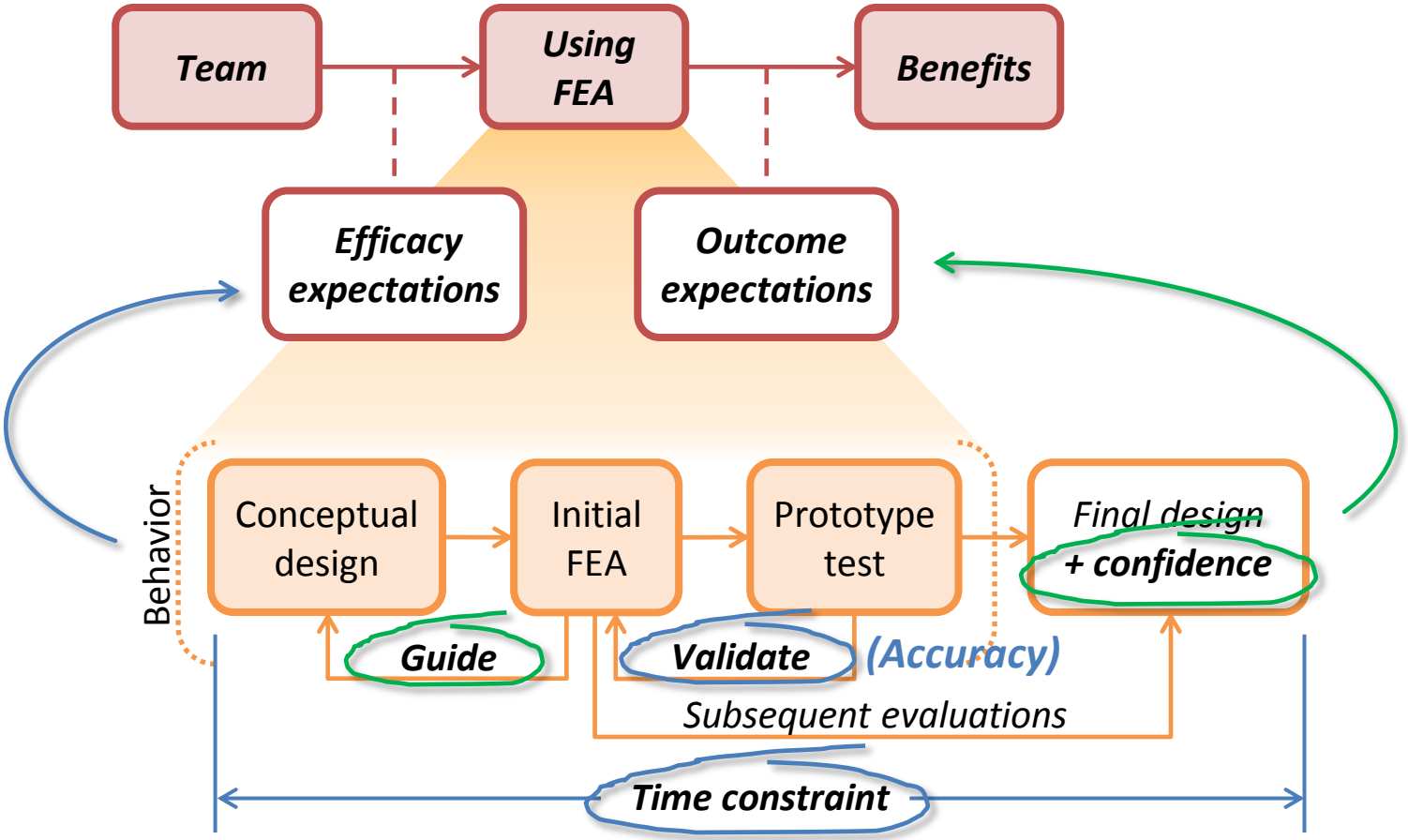
→ Is FEA feasible?

- FEA / test comparison
- Confidence in the FEA analyst
- Time required

→ Why use FEA?

- Improved design confidence
- Tangible product design impacts
- Complement other design knowledge

Confidence model



Difficult to contrive these factors apart from real product development…

…This can be leveraged! Power of positive examples.

Recommendations to Sandia

ENHANCING EFFICACY EXPECTATIONS

- Involve FEA analysts in testing & *ensure visibility of validation evidence*
- Explore co-location of FEA analysts and design teams *to enhance team confidence in analysts*
- Expertly scope FEA to fit project timelines *using a designerly approach*

EXEMPLARS OF FEA

- Target FEA toward product development *where FEA can unambiguously enhance design confidence*
- Demonstrate value added by FEA *even when other sources of design knowledge exist*
- Select exemplars exhibiting significant feedback from FEA *into product design*

Conclusion

CONTRIBUTION

- Addressed gap between FEA's recognized potential and negative perceptions
- Framework describing influential factors for product development teams
- Insight for increasing utilization of FEA and guidance for future diffusion efforts

POTENTIAL LIMITATIONS

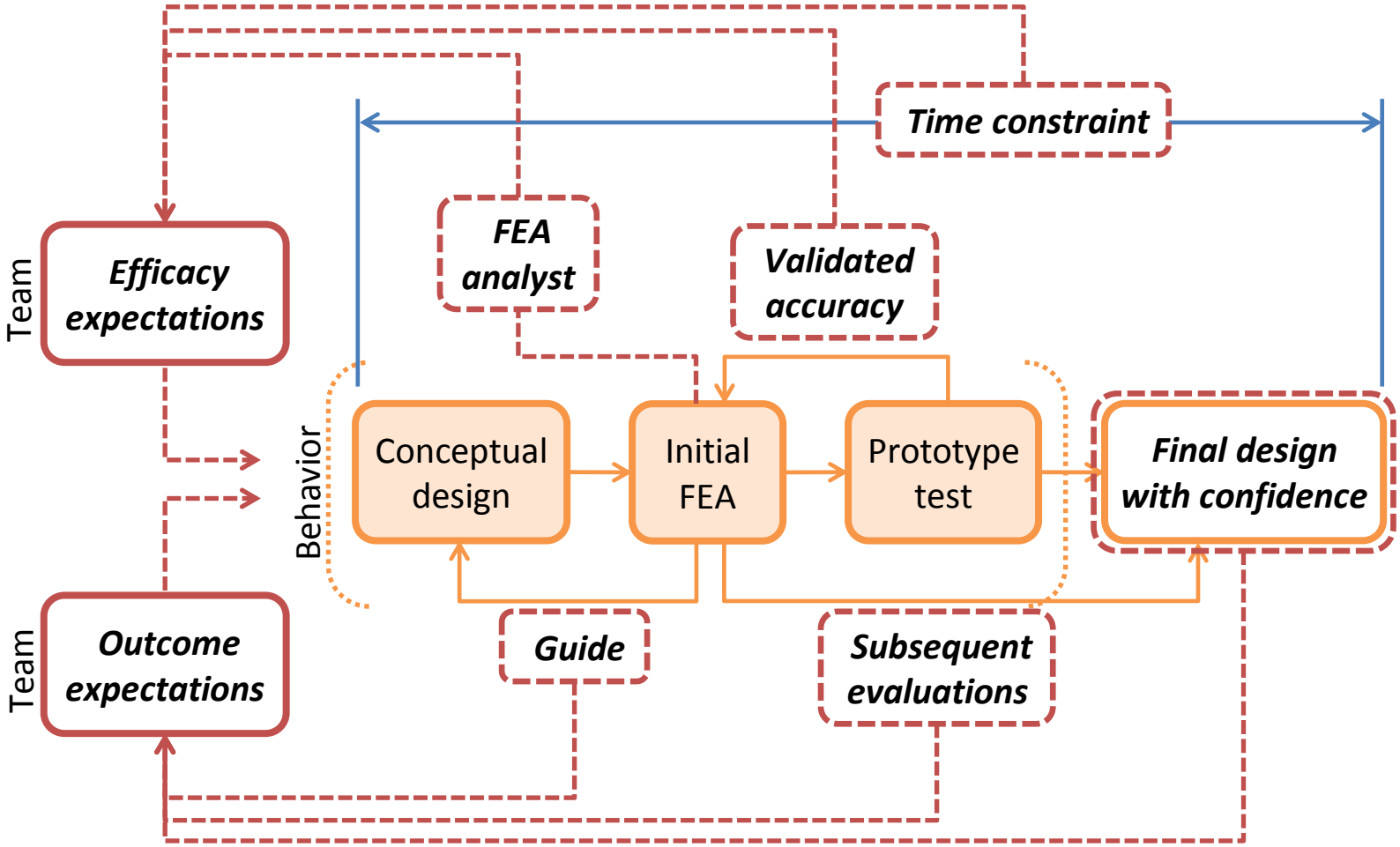
- Potential for participant-observer bias
- Individual researcher

FUTURE WORK

- Additional FEA and simulation technologies
- Other companies and/or industries
- Theory-testing research (quantitative)

Questions

Confidence model



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Dissertation outline

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- Case study 2
  - Design, FEA, prototype testing
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