How Digital Mission Engineering will shape your future defense systems, to increase effectiveness and efficiency

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ABSTRACT

This presentation will describe digital mission engineering — the missing piece in modeling and simulation. Missing, how? It's not enough to simulate components or systems in isolation when most technologies today are interconnected. And the mistake of ignoring the variables of our dynamic world is written throughout history… and legend. Yet too often these conditions and interactions are left out of engineering simulation, with requirements as the only goal.

Digital mission engineering fills this void in modeling and simulation by incorporating the operational environment to evaluate mission outcomes. It's a process of modeling your system as it will operate in its expected conditions, and with or against other systems.

While digital mission engineering might seem like it comes at the end of a project — once your system is designed — the truth is quite different. It should be applied from the beginning and throughout the product life cycle. The model of the operational context that you create with digital mission engineering contributes to your project's digital thread so that you can rapidly evaluate the real-world impact of design changes and share that information across engineering teams. By simulating the world in motion, digital mission engineering provides insights far beyond requirements validation.

1.0 INTRODUCTION TO DIGITAL MISSION ENGINEERING

This paper describes the concept and role of Digital Mission Engineering and its applicability to the design and operation of defense systems.

The notion of a mission is really some important assignment that emphasizes the need for timing and timeliness, some reliance on the quality of the performance of a system in achieving the mission objective and the reliability of that. It's wherever these factors overlap with systems and systems of systems in general. This applies to application areas like national defense, scientific discovery, public safety, search and rescue, but in general, the application of digital mission engineering can apply in more generic ways. For example, for communications infrastructure or for position navigation and timing infrastructure, because those infrastructure elements overlap in these mission areas and are generally evaluated that way. Digital mission engineering can be applied to that as well. With this definition for mission, the engineering part of that then is simply doing the engineering around that, that consists of planning, analyzing, organizing and integrating the assets, systems and capabilities in order to achieve that desired outcome and those desired mission objectives. Digital mission engineering is really just the application of digital means, specifically modeling and simulation to execute this engineering function.

One other relevant aspect to highlight by way of background with regard to the definition of digital mission engineering as it's commonly used, how it overlaps with some of the modeling and simulation activities that go on in the engineering process or in the execution of system operations to execute some of these missions.

What is currently depicted with regards to the Digital Mission Engineering topic are three generically encapsulated areas for modeling and simulation. There's modeling and simulation at the mission level, which produces in the context of digital engineering, a twin that represents the mission environment, the environment that considers where the mission systems are executing and some method for calculating the quality of the outcome for those mission executions. Separately from that, there's engineering, modeling and simulation where we're evaluating performance and functionality. Lastly, as a general category, we have sort of the logical models, the decision-making representations that we capture in a variety of ways, like architecture, automated decision using AI, tactics, techniques and procedures, usually brought ahead by humans, as part of the Digital Mission Engineering Initiative.

The main goal is bringing all of these three together and evaluating how our engineered systems and systems of systems, as we apply our operational procedures to them, are effective or are not effective at executing our mission outcomes. This is what we are identifying as Digital mission engineering.

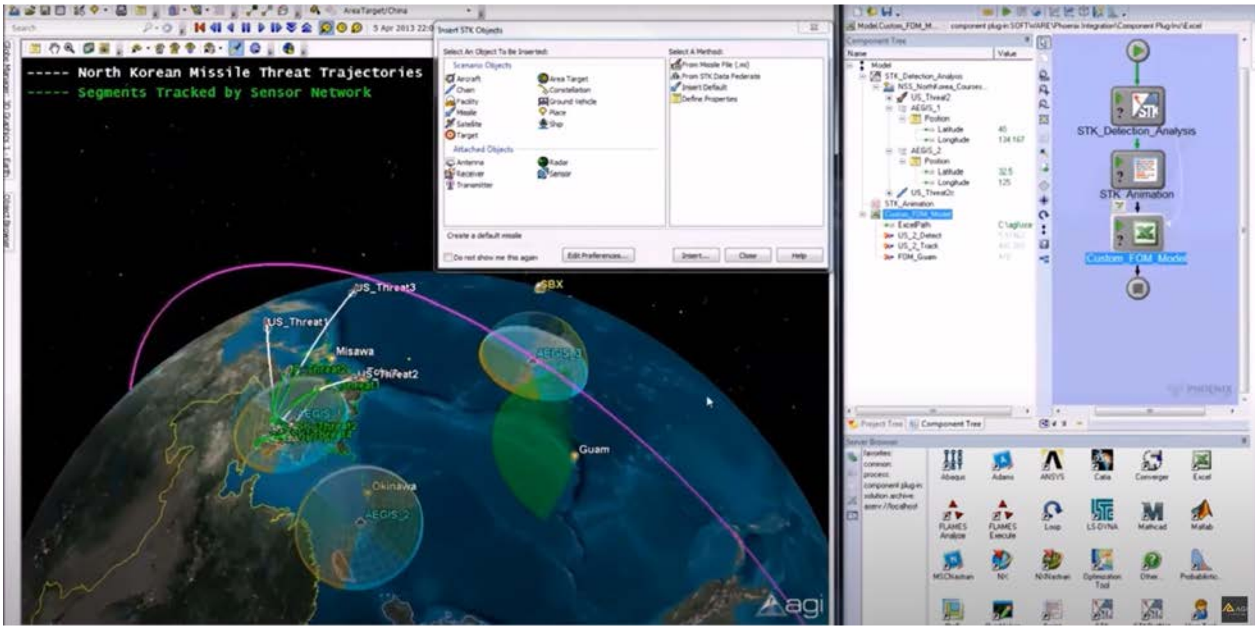

Figure 1-1: Example of mission analysis for multi-domain assets.

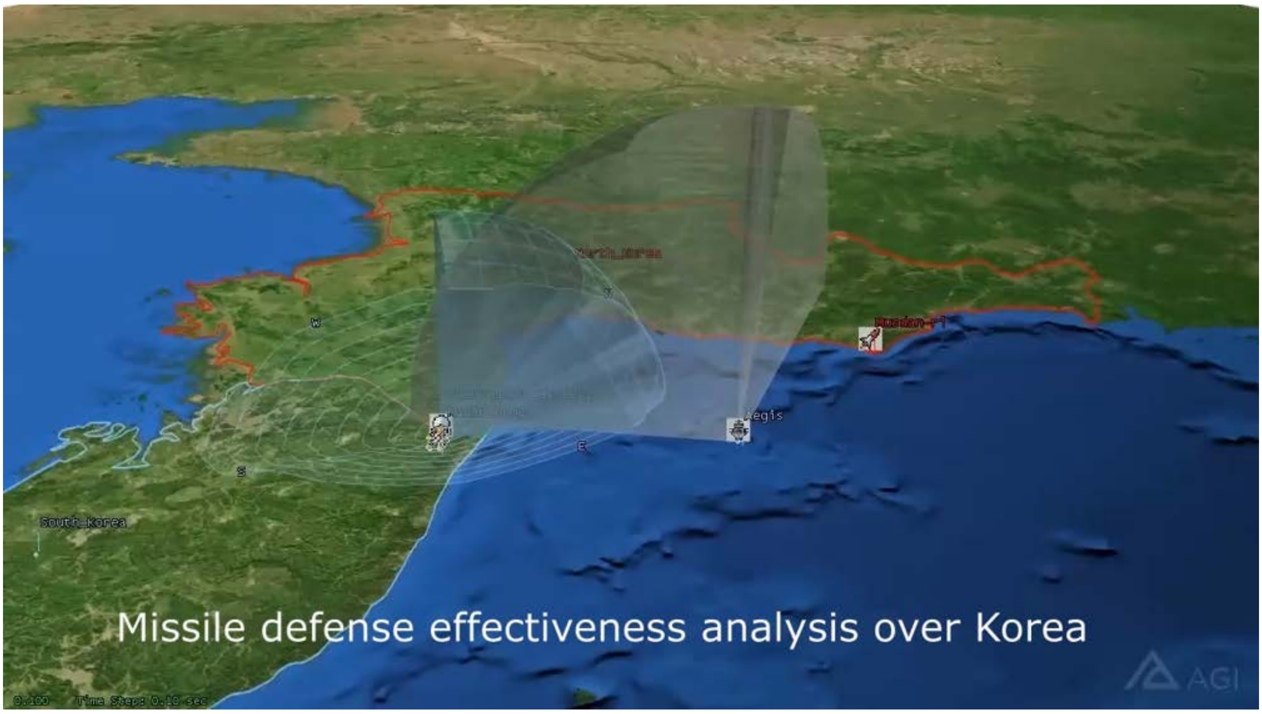

Figure 1-2: Example of mission analysis for missile defense scenario.

An example could be described by figure 1-1 and 1-2 above, in which a theater or global mission can be observed, the environment being encapsulated here in this visualization, the measures of effectiveness being computed with regard to response times of the systems involved, a capturing of the functionality of the radar systems, the missile threats of the spacecraft in this multi domain environment. And the logic that's applied with regard to how these systems interoperate in an adversarial and responsive way or in a coordinated way among the response factors.

1.1 Why is DME important

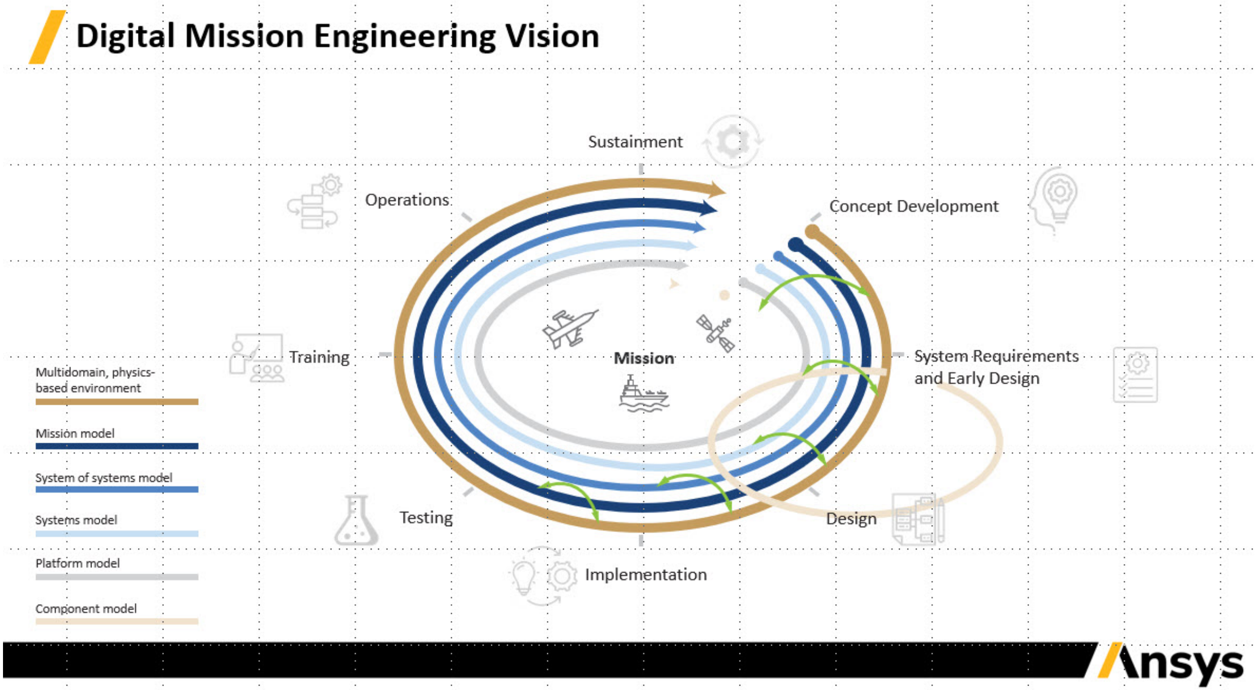

Figure 1-3: Graph highlighting the challenges of digital mission engineering.

Figure 1-3 above describes what is commonly seen happening in the mission, the application areas that was described previously. The systems that we're utilizing to execute our missions and the processes that we use to engineer and deliver the systems and capabilities for those missions are becoming much more complicated. The effort and the time required has gone up to deliver those same capabilities, but at the same time, the demand for responsiveness is being compressed significantly. The time in which we have to identify the need for our mission objective and the definition around that objective has gotten shorter. And additionally, as a result of that, the time that we have to deliver capability that responds to that mission need has been compressed as well. So really what we're trying to accomplish with use of digital mission engineering is addressing these two competing requirements. The complexity is increasing dramatically and at the same time, there is the need to respond with more capability, faster. We see this in a lot of application areas, certainly in the area of national defense. As we think about the threats that we're facing, threats are responding much more quickly. There are techniques being utilized by our adversaries that are asymmetric in nature. They don't require the same amount of time, the level of technology or complication in order to be effective in deterring some of our areas of strength, the use of cyber techniques is an example of that. And our adversaries quickly adapt to our responses. The timescale in which our adversaries or threats can be identified and the difficulties that our current systems and techniques have in responding in a timely enough way to offset those threats, is the biggest challenge; and part of the reason we experienced these conflicts is because largely our response timelines are gated by the practices that we have in place. Some have described it as industrial age pace for our responsiveness, for delivering capability or actually responding with these systems, but these demands aren't limited to national defense alone. Even in the research community for scientific exploration and some of the big science areas, for example, in spite of the growth in the human researcher base, the output, at least measured by publications and new scientific discovery has actually curtailed or gone down. At the same time, the funding for many of these projects has gone down. In the scientific discovery world, there is an impetus not so much to move fast, but to do more with existing or fewer resources and be creative about doing that. And whether we're talking about national defense or scientific discovery, a lot of these, lead to making changes that can largely be described by a curve like this influence effectiveness curve. Essentially what we're showing here is sort of a well-known fact for our complex programs and initiatives that the ability to influence the outcome is highest at the very beginning before we get far down this process.

As we move forward in time and progress through the development of system or the execution of missions, we reach a knee in the curve, after which our ability to substantially change those outcomes really drops off dramatically. If critical issues are encountered late in that progress, our ability to respond is significantly limited and we can only achieve a certain level of effectiveness relative to what we intended initially. The fundamental challenge that we're faced with and the real thing that we're trying to address with digital mission engineering is the following: moving that identification of critical issues as far forward in that process as possible so that we can maximize the total effectiveness delivered and deliver that as soon as possible. The reason why digital mission engineering is so important to that process is because for the kinds of outcomes that we're talking about, everything begins with the mission.
The overall objective is to deliver mission effectiveness and achieve those mission outcomes,so the sooner that we can identify those issues related to the mission definition itself, the engineered systems or systems of systems that are involved or the techniques, tactics and procedures that we're using to execute those missions, the more effective we can be at delivering the right outcomes and delivering them sooner.

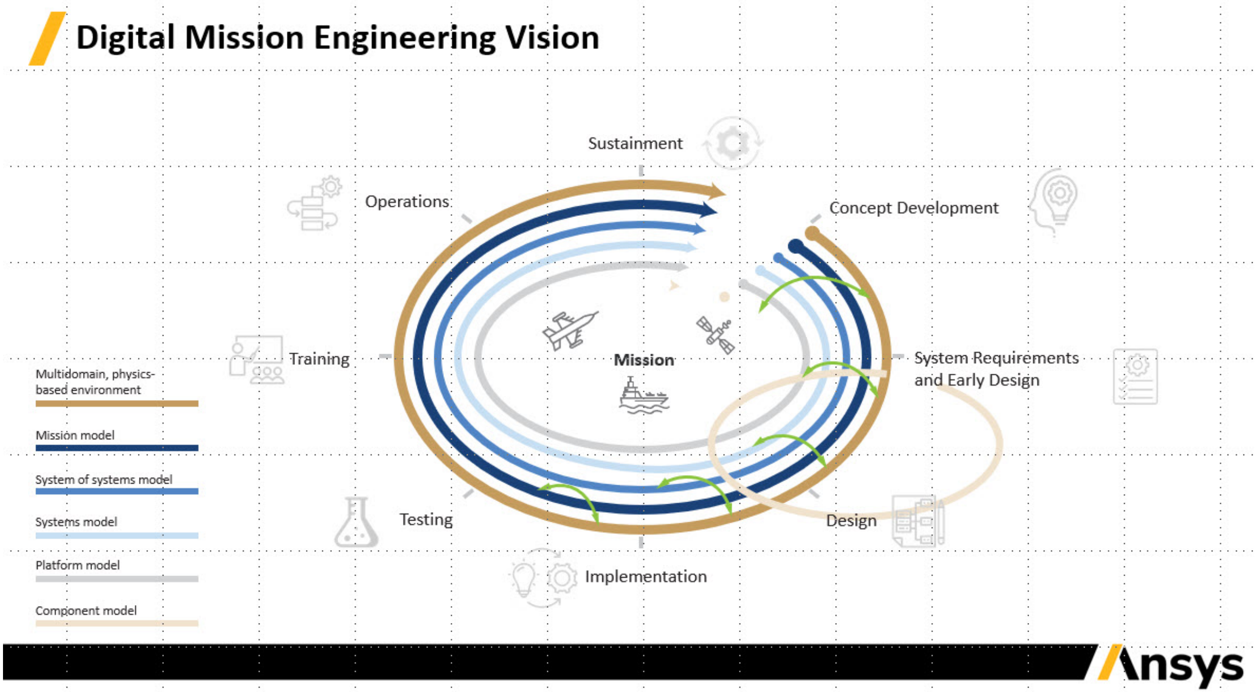

Figure 1-4: Digital mission engineering vision.

One way to look at this, is to look at the development lifecycle for a complex system. In figure 1-4 above, in the representation of the cycle going in a clockwise fashion from concept development through systems engineering, design implementation all the way through testing operations and sustainment, there are really a number of important activities that go on all throughout this life cycle and a number of artifacts that drive effectiveness, especially as it relates to the ability to deliver the desired mission outcomes. Several of those artifacts are represented here as the requirements that we're building our systems to, the models that are used to represent and describe the outcomes that we want, then the physics-based models and simulation that are used to inform our decisions and drive our designs. This graphical depiction captures what we've discerned as we've interacted with the community: our government customers our contractor customers, our consulting customers and largely they all paint the same picture. Looking, for example, at the concept development phase, we can see that we have models represented that describe our system and the physics tools that we use to analyze those models and set our direction, don't cover the entire scope of that and not only that, but they’re also physically disconnected from that process, meaning while the models change, the simulations may not.

This creates sources of error that can creep into the process. Maybe more critical is to notice the gaps that occur and the direct breaks that happen as you transition from phase to phase. In the spirit of identifying issues as early in the process as possible, the fact that these gaps and lapses exist really negates the possibility of making that happen at the earliest stage and additionally, you see that the physics tools that are used are themselves disconnected.

One of the areas where this is overt is in the area of aircraft test and evaluation. Few years ago, we got actively involved in this area. And one of the things that we observed from our customers is, they were struggling with these exact issues and coming to us to see if we could collaborate to produce some successful solutions. What they realized is that by the time these complex systems got to the test and evaluation phase, there was no existing persistent mission model. So that mission demand and objective had to be recreated in the test phase to design tests around. Similarly, the tools that were being used were not well integrated or worked together. And the result of this is that in addition to requiring additional time to rebuild those models, the tools not working together resulted in the inability to pack as much successful testing activity or test points into a given flight as possible.

As the organizations were figuring out what needed to be tested and how to test it, it turned out after analyzing the results, that test had to be re flown up to 50 percent re fly rate. These were some pretty compelling data points that we observed from direct engagement. The good news is over the last several years these organizations have made great strides and we've been happy to participate in that. Implementing some of the digital mission engineering activities that we'll describe here really can deliver some substantial tangible results and do so in a fairly short timeline. Going back and revisit our lifecycle, unlike the broken line model that we saw as it exists frequently today, one of the requirements is that the mission model that established is established needs to meet, be maintained in some way as a persistent model throughout the entire lifecycle, so that traceability back to those mission outcomes at every step in the engineering process and throughout the lifecycle can be maintained. Additionally, there are a variety of models, and these can be descriptive models or calculation analytical models that are developed at different phases.

One of the key things that needs to be done is, to identify those critical issues as soon as possible. We want to bring as much fidelity in that modeling and simulation process as far forward in the process as possible, and that can be achieved using higher fidelity tools and more engineering techniques, earlier in the process, or by utilizing models that already exist for existing systems that will be incorporated into the mission execution in either way. It's important to bring those levels of fidelity forward and do that sooner in the process. Finally, from a mission perspective, a key ingredient, as we identified in that early graphic, is to have a multi domain engineering, physics based mission simulation environment that can integrate all of the various models at the appropriate levels of fidelity so that the calculations can be made as we trade off engineering performance characteristics. The operational techniques, tactics and procedures and the mission objectives themselves. Mission engineering practices within the digital engineering initiative in trying to quantify what the impacts can be, it's a very broad swath of applications and a wide range of outcomes, but in our interactions over the last five years or so, we have been able to quantify some of the things that will contribute.

A conservative estimate for the impacts can be counted up through at least these three particular contributions that the use of digital mission engineering can make. The first of all, what we've experienced and what we've been asked for to help solve is that at an individual systems-engineering level, those working on these kinds of programs in general spend 24 percent of their time rewriting tools when they know other capabilities exist that do the same thing, that's one easy area that can be addressed right away.

Secondly, transitioning from phase to phase in general, we find that 30 to 50 percent of the models and simulations that are created, are duplicates of models or simulations that had been done in prior phases. And finally, as we get to evaluating the measures of mission effectiveness for the mission itself, lack of tool integration at different levels of fidelity and the different functional pieces results in a delay of six times what it could be because so much work has to be done either manually transferring information or writing scripts to overcome those integrations. Depending on how these different factors contribute, when looking at the mission engineering components of that lifecycle, by addressing these issues, you can accelerate the timeline by a factor of two and a half to six or so and that's really what we're trying to accomplish with Digital Mission Engineering.

Another example, for a satellite architecture study, done as an internal experiment to evaluate for ourselves how quickly we could accelerate the engineering process, highlighted the possibility to look at the possible alternative to achieve these kinds of goals, using various type of tools, integrating tools from other commercial providers or tools that exist within any organization that represents a unique IP that those organizations bring to the overall mission design and engineering systems engineering process. Pointing back to that scenario that we discussed earlier, that multi domain missile defense scenario, you can see a trade study being executed with regard to the positioning of different assets and capabilities in that scenario. That trade study being driven by an external set of tools and being integrated with an external model for measures of effectiveness that might be unique to a particular organization. These two examples that were just highlighted, largely apply in the concept development phase.

One of the points that we emphasized about the persistence of the mission model is that it's important to achieve acceleration in all phases of the operation. So if we were to fast forward, for example, to test an evaluation, it speaks to this example that was done for a C range test where the test was looking at tracking and detecting and responding to a particular target. You'll see the target here. The point I want to emphasize about this is that we made the point regarding acceleration and the identification of critical issues sooner in the process that we need to pull fidelity and higher fidelity into the concept designs, whether it's for early phase design or test design. In this case, what was done is we used a software tool to compute the high-fidelity radar cross section for the target under consideration and also generate the as installed antenna patterns that would actually represent the physical performance of antennas on the ship that you just saw. Through this kind of integration, we're able to introduce that full physics level of fidelity very early in the systems engineering process, whether that's for concept design or test planning and another element of the integration of the persistent mission thread can apply to those aspects of the engineering process that aren't even system related.

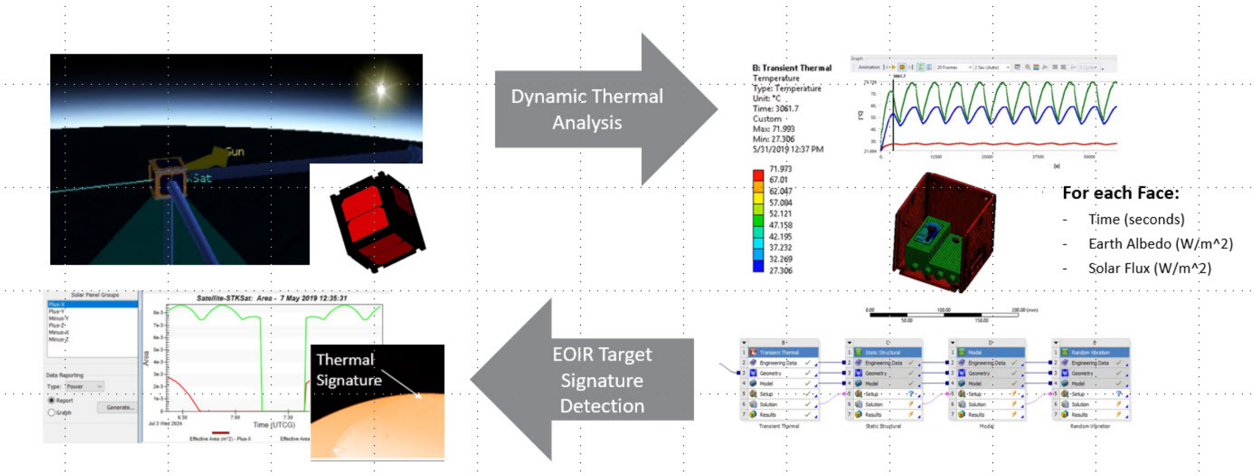

Figure 1-5: Satellite thermal analysis.

In figure 1-5 above, you see another possible use case aimed to evaluate at the thermal analysis for the CubeSat, what you see represented at the bottom are the loading conditions, the thermal loading conditions for the system in general or the subsystems in that environment. What is relevant to emphasize is that the existence of that persistent mission thread allowed these loading profiles to be computed in one tool and imported directly into another tool, highlighting software interoperability. The reality of these kinds of systems, not the CubeSat specifically, but complex missions in general, is that the mission requirements are likely to change while we're in the middle of the engineering process. This connectivity and that persistent mission thread allows us to change our design responses very quickly. And while we're on this graphic, it’s important to mention we're asked to solve a problem jointly using products that we had never integrated before. And the effective time that it took to accomplish that was measured in the span of hours or a day at the most, really representing the kind of acceleration and speed that can be realized when tools are used that are designed from the ground up to operate well in this engineering ecosystem.

The possibility modelling and simulation is providing is to evaluate the mission effectiveness, fed that back into the process and through that technique to create a closed loop evaluation from mission through system, through engineering design, using tools that exist today. We'll certainly hear about future techniques and technologies that are going to help this process even more. But much of this exists already today among some of the tools out in the industry. We've used the engineering lifecycle to highlight some of the techniques that digital mission engineering can accelerate in that kind of process, but throughout the world, as these systems go into operation, many of those life cycles and the products of those systems, engineering processes exist and are working in concert with each other and those organizations and individuals who are responsible for conducting operations or performing operations analysis don't really exist in any one of those circles. Nonetheless, the techniques that we're talking about and the acceleration that can be achieved from digital mission engineering applies to that process as well.

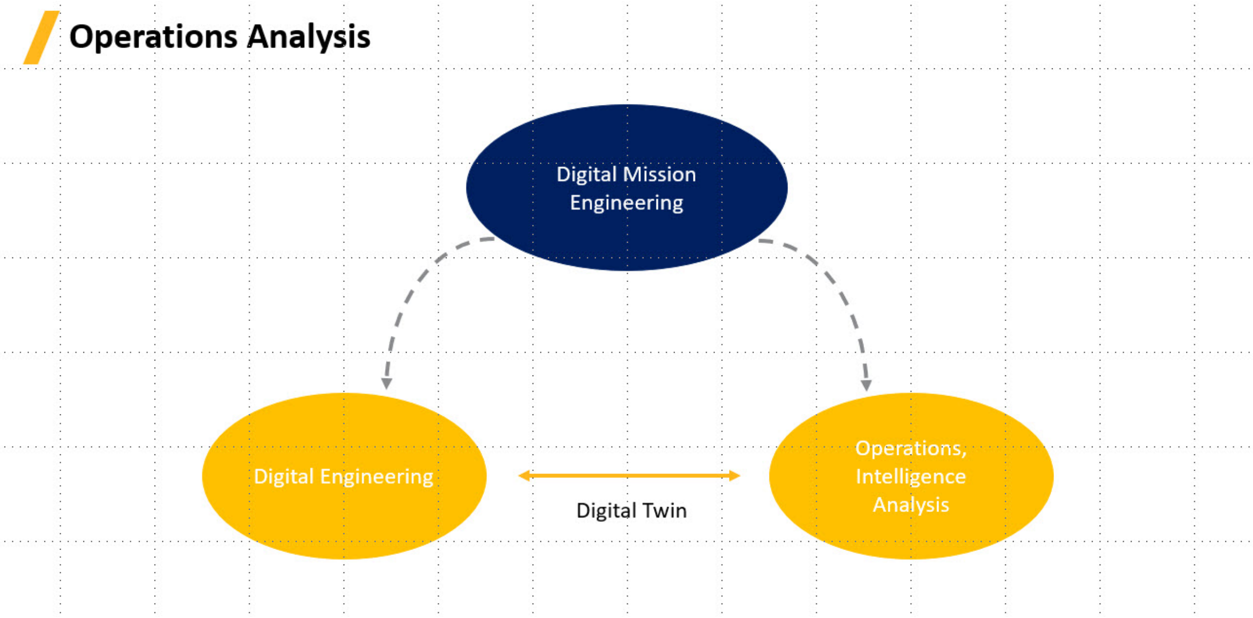

Figure 1-6: Satellite thermal analysis.

What has been discuss about thus far is the role of digital mission engineering, specifically in the digital engineering process or the digital engineering enterprise.

The same techniques, the use of models and simulation at the mission level, the functional performance level, and the logical models as well, combined together are also very effective at executing operations and intelligence analysis, whether that's predictive analysis or forensic analysis. And there is an important relationship between the engineering and development process and the operations and analysis in that operations and analysis can capture models and represent those items that we need to contend with for adversarial forces or uncharacterized activities and provide that back into the digital engineering process, so that our next iteration or our next set of capabilities that we produce, take that into account.
There's an important ecosystem over and above the effectiveness of digital mission engineering that is enabled through the collaboration of the engineering processes along with operations and intelligence analysis.

The role for digital mission engineering is for engineering design, digital engineering in general or operations and analysis, is that it enables the ability to make critical decisions or identify critical issues earlier in the process and leads to a substantial acceleration for the delivery of capabilities or operational decisions.