# Using Realistic Weather to Add Realism to Exercises


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**ABSTRACT:** *Historically, military training exercises haven't integrated weather very well. Generally, exercises use weather to control pace. If Blue Forces seem to be winning too quickly, exercise controllers "crank up" the bad weather. Occasionally, controllers use weather to cause an effect such as placing a thunderstorm over a base to preclude takeoffs. In both cases, exercise weather may not be realistic or consistent. In other words, real weather generally doesn't change suddenly without some indication giving planners/trainees something to consider while planning. Granted, in real life, weather may not resolve exactly as forecasters predict, but at least planners/trainees understand the possibilities and can formulate ways to mitigate or exploit weather effects. The Department of Defense (DoD) Air and Space Natural Environment (ASNE) Modeling and Simulation Executive Agent (MSEA) recently integrated new processes and technology to increase weather realism in AUSTERE CHALLENGE 06 (AC06), an operational level evaluation that incorporated live, virtual, and constructive elements into the federation. In AC06, exercise objectives drove the weather scenario, which complemented training instead of dictating specific responses. This paradigm can be integrated into other DoD exercises to augment training while enhancing realism. This paper describes the process and technologies used in AC06 as well as future enhancements to make weather more realistic in exercises.*


## 1.Background

### 1.1.Project origins

Be careful what you say about what you can deliver. Someone may actually believe you and expect you to prove it.

Such was the case when we presented our role and tools to the Warrior Preparation Center (WPC) at Einsiedlerhof AS, Germany in the fall of 2005.

As the Department of Defense (DoD) Air and Space Natural Environment (ASNE) Modeling and Simulation Executive Agent (MSEA), the Modeling and Simulation Division of Air Force Combat Climatology Center (AFCCC/SM) develops technologies to enable models and simulations (M&S) to incorporate realistic and consistent atmospheric and space weather.

Environmental Hypercube, one of the tools we described to the WPC, caught their attention. Coincidentally, the staff received a presentation on Hypercube from the developer a week prior, which piqued their interest. Thus, when we came in touting the extraordinary possibilities of incorporating realistic weather play into exercises using Hypercube, the WPC was ready to call us to task.

Unfortunately, we explained, Hypercube was still in development and had gone through little more than a proof of concept. Still the WPC persisted and leadership asked to be the "operational test bed" for integrating Hypercube. In fact, they set a target of AUSTERE CHALLENGE 06 (AC06), less than a year from this initial meeting. What's more, integration tests for AC06 were a mere 5 months away!

### 1.2. AC06 purpose and objectives

AC06 was a Chairman, Joint Chiefs of Staff (CJCS) exercise to test the ability of US Air Forces in Europe (USAFE) to rapidly transition from peace-time to "warfighting headquarters". The focus of the "warfighting headquarters" under Air Force's transformational concept is to produce a consolidated Air Tasking Order (ATO) for all theater flight operations.

Even though AC06 would ultimately be an evaluation, it included several spin-up events to train Air Operations Center (AOC) staff. According to CJCSM 3500.04 Universal Joint Task List (UJTL), weather is a principle condition (C1.3) in developing command Joint Mission Essential Task List (JMETL). Units and individuals should be training to perform specific tasks under conditions they are most likely to encounter, to include environmental conditions. In addition, mission success is highly dependent on weather (e.g., visibility affects sensor performance). Therefore, AC06 planners decided early to include an objective to force exercise participants to make decisions to mitigate or exploit the effects of weather when generating the ATO. While not a novel concept, this objective would be supported through more rigorous, realistic, and automated processing than previous exercises.

Nothing can change the pace of war faster than weather. It directly affects five of the principles of war—mass, offensive, surprise, economy of force, and maneuver. Yet, it can't be controlled or perfectly predicted. Thus, military leaders can certainly become slaves to it. On the other hand, these leaders should be trained to account for the effects of weather—to devise ways to mitigate its effects and to exploit opportunities presented by the weather. Unfortunately, weather generally only arbitrarily controls the pace of exercises without regard to producing coherent physical effects. For instance, if Blue Forces appear to be winning too quickly or slowly, exercise controllers arbitrarily "crank in" bad or good weather, respectively. Weather changes don't even have to be realistic or even gradual.

This is not to say weather has been ignored in exercises. On the contrary, weather officers always participated in daily briefings and ATO planners built plans based on the forecast. However, simulations lacked the ability to enforce proper planning along with the capability to affect the outcome of appropriate missions. Exercise controllers had to manually manipulate simulation results to account for weather. Depending on the magnitude and/or subtlety of the effects, controllers may not even change the right missions. Thus, negative training occurred.

AC06 planners wanted to ameliorate this and found just the right technology from the ASNE MSEA office.

### 1.3. ASNE MSEA roles and tools

#### 1.3.1. ASNE MSEA responsibilities

In 1996, the Undersecretary of Defense for Acquisition and Technology (now USD(AT&L)) designated the Air Force as the ASNE MSEA. While the Air Force Director of Weather is the authority behind ASNE MSEA, he has delegated day-to-day responsibilities to the ASNE MSEA office to do the following:

- Coordinate all aspects of DoD M&S related to representations of the air and space natural environment
- Define program objectives for short and long-term requirements
- Establish standards and procedures to facilitate interoperability and reuse of air and space natural environment products
- Provide future direction for cost-effective, just-in-time (JIT) requirements of ASNE

For the most part, this means ASNE MSEA must be the office of primary responsibility within DoD for processes, tools, reference databases, and networking capabilities with respect to the ASNE used in M&S.

The ASNE MSEA office had been supplying representations of the atmosphere for a while prior to AC06 using a tool called Environmental Scenario Generator (ESG). However, they found legacy M&S couldn't always process the data. As a result, they began a project to generate weather effects called Environmental Hypercube.

### 1.3.2.ESG

Primarily, ESG searches historical or modeled environmental databases to find user-defined scenarios. To do this, ESG employs fuzzy logic search techniques to locate the best matches to the desired scenario. It then generates a custom dataset containing the specific content required to support the simulation, for delivery in standard formats to include SEDRIS, gridded binary (GRIB), and comma separated values (CSV). ESG technology was developed to be domain neutral, and can easily be applied to new data and model resources, or be extended to support new data types and formats.

The ESG System, as deployed at AFCCC, consists of several components:

- Storefront—general information on ESG concepts and capabilities, description of ASNE MSEA, contact information, etc.
- Applications—ESG provides multiple community focused web applications, as well as some desktop tools for use with ESG delivered data.
- Infrastructure—the ESG processing engine, that can be utilized command-line, via the web applications, or via web services.
- Data Resources—the AFCCC site focuses on atmospheric and space resources, but also contains some ocean and terrain archives. Additional resources can be added locally or at remote sites.

Registered users can access a web-based version of ESG and generate datasets, but ASNE MSEA recommends customers go through our subject matter experts (SMEs) until they gain an understanding of the tool's purpose, capabilities, and limitations. Basic information and account application exists at https://esg.afccc.af.mil/. Currently, only government persons and those working on DoD projects can get ESG accounts.

ESG is also designed to facilitate the Integrated Natural Environment Authoritative Representation Process (INEARP) [1], which tries to ensure consistency and coherency between environmental domains (i.e., atmosphere, ocean, terrain, and space). For instance, if it's raining, the ground is wet; seas aren't calm when it's windy. However, we have focused primarily on atmospheric data during ESG development. Space, ocean, and terrain data should be added in the future.

The data from ESG can be used by physics models to produce effects and/or drive realistic behavior models within simulations. In the case of distributed exercises, the data can be pre-distributed to each simulation, or can be distributed at runtime by a federate. However, ESG technology does not directly address these issues; its focus is on providing physically consistent representations of the natural environment, in a form ready for use in simulations.

### 1.3.3.Desktop Data Viewer (DDV)

The DDV was developed as a simple way to visualize ESG data sets. The DDV application works directly with the CSV files produced by ESG and can optionally integrate correlated weather graphics produced by ESG or otherwise. The tool provides for basic spatial and temporal inspection of the ESG scenario data set including a time series visualization capability. Future enhancements to the DDV will include embedded spatial graphics generation capabilities.

### 1.3.4.Environmental Hypercube

Ultimately, for weather to be considered included in M&S, simulations must ingest environmental data, produce effects, and modify behaviors accordingly. In an operational exercise like AC06, the outcome would show the correct response to planner decisions when considering the weather (i.e., a poor weapon/weather combination would have a marginal chance of success). Weather influences sensor effectiveness, route selection, transit time, logistics, and a myriad of other factors. Alas, very few simulations have the ability to deal with weather data. Producing realistic effects can be prohibitively expensive in terms of runtime performance, and modifying entity behavior algorithms can become very complex. As a means to assist simulation developers in incorporating environmental effects, ASNE MSEA sponsored the development of the Environmental Hypercube.

The Environmental Hypercube captures the effects of the environment on a particular class of weapon system by providing a performance metric as a function of tactical parameters. For example, an IR sensor system might be characterized by its Probability of Detection ($P_d$) as a function of viewing angle, sensor altitude, target type and location, and time of day. A physics model is then used to pre-compute the $P_d$ values for each combination of parameters, storing the result in a multi-dimensional lookup table, or Hypercube. In this example, the influence of weather is introduced through the target location (Latitude and Longitude) and time of day dimensions as inputs to the physics model computing the IR sensor performance. This Hypercube then enables simulations to access a realistic performance metric in milliseconds that is based on realistic physics applied against a realistic environment representation.

While in development, the Environment Hypercube project has leveraged the physical models provided in the Target Acquisition Weather Software (TAWS) mission planning application as the basis for generating Hypercubes representing IR, Laser, and TV sensor performance. However, the Hypercube technology itself is completely independent of the physics model chosen for use. Additional Hypercubes for performance metrics such as Probability of Kill ($P_k$), trafficability, and Cloud Free Line of Sight (CFLOS) are all being investigated.

In order for the Hypercube to be used, the simulation must modify some aspect of its behavior algorithm for the weapon system of interest. Referring again to the example above, the IR sensor detection algorithm within the simulation would have to be modified to query the Hypercube for a $P_d$ value, providing values from the simulation for the tactical dimensions on which the Hypercube was constructed. The Hypercube can be accessed via an extremely small C application programming interface (API).

The Hypercube Display tool is a Microsoft Windows application for the graphical inspection of a Hypercube. It allows the user to manually set values for one or more dimensions and then visualize the performance metric as a function of the unconstrained dimensions. The current version supports the optional inspection of the weather data files that were used by the TAWS models in producing the Hypercube, resulting in the ability to inspect both the performance metric and the weather that impacted it.

Simulation operators can use the Hypercube Display tool to aid in determining weather-affected sorties. The tool could also be used by exercise white cells when adjudicating or justifying results.

### 1.4.Air Warfare Simulation (AWSIM)

AWSIM is the official US Air Force theater-level wargaming model. The purpose of AWSIM is to provide a training capability for the air warfare environment. In fulfilling this purpose, AWSIM represents the air component of commander-level battle staff training for Air Force conducted exercises, and the air portion of joint training exercises.

AWSIM is an interactive and prescriptive, computer-driven, time-stepped simulation of a theater air warfare environment. AWSIM is latitude and longitude based and simulates day and night operations and limited weather conditions over a smooth earth (no terrain). It supports a two sided scenario where opposing sides define, structure and control their forces.

Modeled features include aircraft, air bases, surface-to-air missiles, short range air defense systems, ships and radar sites. AWSIM results include success of individual aircraft missions, munitions consumption, and the systematic playing out of a scenario based on kill algorithms that determine the outcome of many separate aircraft interactions. [2]

AC06 used AWSIM as the principle simulation to analyze the ATO produced by the AOC staff. Unfortunately, AWSIM could not account for weather. Any weather-effected mission would have to be manipulated (i.e., canceled) after mission completion. Hypercube overcomes this very drawback.

Formerly, AWSIM target engagement behavior occurred as follows:

- An aircraft entered a “kill zone” and requested a target list within a certain radius.
- AWSIM assumed that the aircraft could detect all of the targets, and the decision to engage a certain target was based entirely on proximity and/or value assigned to the targets.
- Once the aircraft decided which target to engage, it changed course and entered the “kill algorithm” (not discussed here since that behavior wasn’t modified by Hypercube).

Notice the algorithm didn't include any consideration for weather. By introducing the use of the Hypercube, AWSIM would now be able to utilize realistic Probability of Detection ($P_d$) values for the specific sensor and targets involved. The target engagement behavior was modified as follows:

- The aircraft still requests a list of targets within some radius from its location, and decides which target it would like to engage based on its proximity and/or assigned value.
- For the "selected" target, a $P_d$ value is obtained via a call to the Hypercube that specifies:
  - Target type and orientation
  - Target location (latitude, longitude)
  - Time of day
  - Azimuth and range of the sensor-target orientation
  - Altitude of the sensor
  - Sensor type
- AWSIM then generates a random number (0 to 1) and compares it to the $P_d$. If the generated number is below the $P_d$ value, the target is detected and the aircraft continues with the existing AWSIM engagement behavior. Otherwise, the aircraft flies closer and AWSIM repeats the queries until the aircraft either detects or flies past the target. If the aircraft never detects a target, it returns to base with unexpended ordnance.

Note that the Hypercube does not impact the probability of killing the target once it is detected. Instead, AWSIM models probability of misfire, hang-fire, hit, and damage and calculates a probability of kill ($P_k$) from within the simulation.

Modifications and testing of AWSIM proceeded methodically. Initially, AWSIM was only changed to allow it to make calls to an underlying Hypercube (i.e., no processing of Hypercube result). In fact, only two sensors were used to generate the Hypercube and only ground attack missions were affected. Tests showed no significant performance impact to AWSIM. Based on that result, developers modified AWSIM's target detection algorithm to include the target engagement behavior to all missions. AWSIM also needed to be modified to include a logging capability to quantify the behavior introduced by including the Hypercube environmental effects. Nevertheless, Hypercube did not slow operations or produce undesired effects.

Testing got a little more aggressive as the modified version of AWSIM was incorporated into AC06 integration tests. The percent of the missions were fittingly affected due to weather, yet processing time was essentially unaffected.

After passing the tests, the Hypercube-enabled AWSIM was approved for AC06. Nonetheless, it retained the ability to turn the weather (via Hypercube) off and on.

## 2.AC06 processes

AC06 stands out as the first AOC exercise in which the weather injected into the computer simulation driving the exercise was the same as that provided net-centrically to the exercise participants. This brought realistic dynamic targeting and execution due to simulated changing weather. The process employed set a paradigm for realistic weather play in future exercises.

Weather didn't drive the exercise, but it enhanced exercise objectives. Actually, the objectives drove the weather scenario along with the format and architecture. Exercise planners wanted to challenge but not overwhelm the AOC to think out of the box and attain specific effects despite weather. They also wanted participants to use as many of their real-world systems including their weather system to maximize AOC training. The ASNE MSEA team went to work to coordinate this.

AC06 planners got more specific on the weather scenario when pressed by ASNE MSEA. They asked for no significant weather effects to operations on day one to allow the AOC to get into a "battle rhythm". The next day, they requested "bad" weather to stress the AOC. ASNE MSEA defined "bad" as low visibility, high humidity in the projected target area so infrared sensors would be degraded. This would complicate the generation of the ATO, causing AOC planners to look for inventive ways to bring about necessary effects. The remainder of the exercise would be fairly benign weather. In spite of this, planners wanted the ability, with around 8-12 hours notice, to "change" the weather so that it reflected any exercise director requirements to impact the training audience.

We used the search power of ESG to find a sequence in history across the area of interest that matched the AC06 desired scenario. This was the first time for ESG to be used to find conditions desired for a major exercise. We found three specific instances of the scenario that matched the seasonal timeframe of AC06. We then verified target area conditions using the DDV and archived weather satellite images. All dates looked good, but one stood out as the best. We asked the 21st Operational Weather Squadron (21OWS) for their opinion of the dates. They analyzed their archived products and agreed with our recommendation. They also collected all the standard briefing graphics associated with the dates so the weather exercise participants could reuse them rather than spend valuable time recreating them. In addition, AFCCC supplied historical observations in an XML format so raw data would agree with graphics yet integrate with the AOC's Joint Weather Impact System (JWIS). The only modifications made to on-hand data were to make the date stamps coincide with AC06. Once this was completed, all products fit seamlessly into the existing architecture demonstrating a keen ability to support future net-centric operations. This process saved hundreds of man-hours searching for the right scenario and constructing products. On top of this, all products seen by exercise participants were guaranteed consistent and realistic. Yet we had much more to accomplish to ensure federation results agreed with this scenario.

Once we found the scenario dates through ESG, we ran a higher resolution weather model of the exercise area so we could generate the proper effects via Hypercube. The model output was then processed through ESG to produce a data set with the proper content for TAWS calculations, and output in the TAWS required format. Then Hypercube went to work to build the effects tables. The TAWS weather files and resulting Hypercube data files were provided for use with the Hypercube Display tool, while the date-stamped Hypercube data files were delivered to the AWSIM cell at JFCOM.

The ESG produced data set was also used to manually prepare a weather data file, in the form of an Excel spreadsheet, for use in Joint Conflict and Tactical Simulation (JCATS), the only other simulation in the federation that could process weather [3], so it would yield results consistent with AWSIM. This chain of events created the electronic data to link exercise weather products to simulation behaviors and white cell adjudication/justification.

During the exercise, controllers distributed weather products at times to agree with the inputs to the federation. Questions from participants were addressed via the exercise chat system. Discussions included possible consequences of weather.

While these processes were ad hoc, they successfully met AC06 objectives. What's more, they're repeatable.

## 3.Results

Overall, weather play turned out to be a huge success in AC06. Not only was the scenario realistic and challenging, it generally had consistent results across almost all aspects of the exercise. The AOC did generate an ATO that mitigated the effects of "bad" weather and exploited "good" weather. For a few of the missions, they chose to accept the risk of betting against weather and had consequences--missions returned with unexpended ordnance because the weather effect included in AWSIM precluded detection of their assigned targets. What's more, this occurred without any external controller manipulation.

On the technology side, Hypercube was proven to be extremely robust, without any evidence of adverse impacts to the AWSIM Federate throughout the 8-day exercise. AWSIM processing time wasn't impacted at all despite over 100,000,000 calls to Hypercube (over 300 calls per second at some points in the exercise). Stressing AWSIM even more, each call included a corresponding write to a log file for post exercise evaluation.

For the first time ever in a major exercise, there was a systematic connection established between the data being played inside the simulations and that being briefed by the OWS supporting the exercise. This was accomplished through the provision of consistent gridded and observational data sets that contained a scenario depicted in the OWS archives. In the future, the goal will be for ESG and related technologies at AFCCC to be able to generate the entire suite of gridded, observational, and graphical data sets required to support an exercise.

The results of including weather in JCATS were mixed. While the basic concept worked, the requirement for manual entry of the weather per the script led to problems during the exercise. As a result, JCATS had some results with respect to weather that differed from AWSIM. During one period in particular, the JCATS simulation was "stuck" on bad weather, while the script had moved on to improved weather conditions. The ground became saturated and trafficability was degraded by 80%, much worse than what should have been caused by the weather scenario. Ground forces became bogged down. The result was that JCATS entity behaviors during this period were not consistent with the weather being briefed, or that being played in AWSIM. In order to improve overall consistency, JCATS should be modified to respond to a dynamic weather script, whether by Hypercube or other means.

The disparity between JCATS and AWSIM resulted in a decision to default to a "benign weather" Hypercube for a short time. Regrettably, the ATO being executed was planned for marginal weather so AOC planners were a little upset about their wasted efforts. While this sort of decision is often a reality in exercises, it shows the need for a centralized weather server to ensure all federates receive a change.

An additional known deficiency was that Intelligence, surveillance, and reconnaissance (ISR) assets weren't affected by the weather scenario at all. In fact, they were 100% effective even when the scenario called for "bad" weather. The problem was that the Air and Space Constructive Environment Information Operations Simulations (ACE-IOS) doesn't currently have any weather capability. It would require code modification similar to what was done to AWSIM to allow Hypercube to interject weather effects. However, the exercise controllers came up with an ingenious work around--slew the sensors skyward when the weather was "bad". This caused the ISR graphics to appear blank as they would in "bad" weather. This is exactly the kind of work around that we would like to avoid in the future by formally introducing weather into all simulations supporting the exercise.

Overall, these results validate the technical approach used for introducing realistic weather effects into an exercise simulation, while also highlighting the need to ensure all simulations making up a federation have a consistent approach to including weather. Including weather in only a few of the simulations can still be viewed as an improvement (as compared to manual tinkering in all of the simulations, which is itself very prone to inconsistencies), but until such time that all the simulations in the federation have a similar approach, attention must be paid to coordinating all weather related interaction within each simulation, both *a priori* and during execution.

## 4.Future

So what are we planning for future enhancements? In general, more integration of weather into exercises by less manpower intensive means. The ASNE MSEA vision is to provide exercise planners with a simple interface that provides a choice of weather scenarios and a menu of products which can support the exercise at both the simulation and controller level. The preparation and distribution of these products would be via the net-centric architecture supporting operational warfare.

We're trying to make the process much simpler in the future. For instance, an event coordinator would submit objectives for an event. Those objectives would be rendered into a corresponding environmental scenario through ESG. As an option, exercise planners could choose "typical", "benign" and/or "poor" conditions for the exercise timeframe and area of interest. The data would then be distributed to event participants (federates and staffs) in products to suit each end user. Any changes to the scenario would similarly affect all simulations and displays/briefings.

The milestones along this path are the automatic generation of model-derived products, further development of the hypercube technology, and the development of a weather data and effects server for runtime distribution.

The first milestone, model-derived products, refers to the observations, satellite and radar charts, Terminal Aerodrome Forecasts (TAFs) or aviation routing weather reports (METAR), and any consequential products required to support the exercise weather staff. This tool would leverage the power or ESG to eliminate the man-hours needed to search for historical data and products or to manually create them. In addition, data and products would all be consistent with the modeled data as this is the source for constructing them.

Next, Hypercube will be broadened. In AC06, only one IR sensor on the air side was affected by weather and only for air-to-ground missions. We're working to expand models from a few sensors in TAWS to space models and weapons effects models. Then we want to integrate Hypercube into more simulations to make weather more realistic and consistent in exercises. Of the entire federation in AC06, only AWSIM was able to directly use weather effects data in an automated fashion through the use of Hypercube. Some effort was made to allow JCATS to see the same weather as AWSIM, but with limited success. In that case, data had to be input manually and resolution differed with AWSIM/Hypercube. In addition, ISR, air-to-air, air-to-ground (other than those with the affected sensor), etc. missions showed no effect with regard to weather. Thus, while weather could no longer be ignored by exercise participants, it wasn't fully integrated.

We envision all federates yielding consistent outcomes. To achieve this, simulations will have to modify behavior algorithms to respond to weather effects. One efficient means of doing this is through the use of pre-computed Hypercube data sets. Regardless of the how the weather effect and resulting behavior is modeled in the simulation, it must be done based on a common underlying environment representation such as is provided by ESG. Buy-in from federate developers is the key to success, resources become the challenge. Fortunately, we can leverage our success with AWSIM.

Finally, our future efforts will endeavor to create a weather data and effects server, which will facilitate a machine-to-machine capability. It will act as host for all environmental information (i.e., modeled data, derived products, and Hypercube effects) with the ability to share and disseminate available data. It will also allow seamlessly embedded calls and facilitate remote access so all federates in an exercise could access the authoritative source data and bear coherent results. This would help alleviate the problem we had in AC06 with disparate inputs/outputs between AWSIM, JCATS, ACE-IOS, and the AOC.

## 5.Conclusion

In the end, our goal is to make sure the warfighter receives the best training possible. We seek to preclude negative training by removing subjectivity and the potential for human error. We showed in AC06 how assimilating a realistic weather scenario and incorporating the Environmental Hypercube can complement exercise objectives. We discovered areas requiring improvement and devised plans to affect the most significant issues.

AC06 paved the way to integrating realistic and consistent weather effects in training. We plan to leverage this success and shape the conduct of training exercises with respect to the environment and its effects.

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## Author Biographies

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**DOUG BROOKS** is a DRC contractor working with the ASNE MSEA team as a liaison to the Air Force Agency for Modeling and Simulation (AFAMS). He is a retired USAF weather officer with over 37 years experience in weather support to military operations, including nine years in modeling and simulation as the ASNE MSEA liaison to the Joint Simulation System (JSIMS), AFAMS, the Joint Warfighting Center (JWFC), and the Joint Rapid Scenario Generation (JRSG) program. His military experience ranges from command of a weather squadron with 21 detachments supporting Air Force and Army units throughout Europe and the Middle East to research and development to model atmospheric effects on ablation of ballistic missile reentry systems while at the Air Force Cambridge Research Laboratory. He has bachelor and masters degrees in meteorology from the University of Oklahoma College of Engineering and is a graduate of the Air War College and the Army Command and General Staff College.

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