# Applying Aerospace Technologies to Current Issues Using Systems Engineering: 3rd AESS Chapter Summit

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## INTRODUCTION

The Institute of Electrical and Electronics Engineers (IEEE) Aerospace and Electronics Systems Society (AESS) Chapter Summit provides a forum for the AESS Chapter Chairs to discuss professional, societal, and managerial concerns in order to improve AESS information flow to and from the chapters for the benefit of our members. On August 18th, the 2011 AESS Tri-Annual Chapter Summit went a step beyond with an investigation of systems engineering analysis of emerging AESS topics. Maybe we should say, eight steps beyond, with topic initiation, background investigation, initial systems engineering analysis of key attributes, presentation preparation, group discussion and clarification, prioritization, external review, and summary of topic research prioritization. The key developments include (1) identifying IEEE topics of interest to AESS readers with IEEE humanitarian goals, (2) evaluation of these topics in a systems engineering analysis, and (3) coordination of a three-step exercise analysis. The value of this Summit for AESS developments was the generation of 30 topical studies, the topical group assessments, and the team recommendations.

## BACKGROUND

From the AESS Board of Governors' meeting in April 2011, a goal was established to utilize the expertise of the AESS Chapter Chairs to expand on the technical improvements for the AESS society during the 3rd Chapter Summit. The 1st Chapter summit was held in Tampa, FL, in 2005 and the 2nd Chapter Summit was held in 2008 in Quebec City, Canada. The technical goal of the 3rd Chapter summit, held in San Francisco, CA, in 2011, was to develop a systems engineering analysis of emerging IEEE topics and their relations to AESS. Attendees that participated in the summit are shown in Figure 1. Key AESS Board of Governor (BOG) leaders helped to coordinate and facilitate the event, including Roger Oliva and Ron Ogan as well as Iram Weinstein, Judy Scharmann, Jim Howard, and Robert Lyons, Jr.

AESS-associated research topics, as listed in Table 1, had already been under assessment as related to AESS readers and were thought suitable for a systems engineering analysis. Given the relative success that the AESS Washington, DC/Northern Virginia Chapters had in pinging members for solutions to the Deep Horizon Gulf Oil Disaster, we believed this Summit/International Group of AESS Chapter Chairs would rise to the challenge of "solving" or at least prioritizing the emerging trends in AESS-related activities. The research list, shown in Table 1, evolved and was divided among 2 teams of 4 groups each when the 3rd AESS Chapter Summit agenda was published in June 2011, and the AESS Chapter chairs volunteered for the various topics.

**Figure 1.**
Third Chapter Summit Team (alphabetical listing) Adel M. Alimi, Ken Bandelier, Erik Blasch, Eli Brookner, George Dean, Yves DeVillers, Reza Dizaji, Murat Efe, Mark Gober, Hugh Griffiths, Chundra Gupta, Ram Gopal Gupta, Jim Howard, Kost Illyenko, Stephané Kemkemian, Kathleen Kramer, Young Kil Kwag, Bob Lyons, Tyler Marshall, Ali Nabavi, Ron Ogan, Eun Oh, Roger Oliva, Michael Orlovsky, Fotinit-Niovi Pavlidou, Andrew Piotrowski, Luis Riesco, Firooz Sadjadi, Judy Scharmann, Vincent Socci, S. Zafar Taqvi, Rick Tuggle, Shunjun Wu, and Felix Yanovsky. Not shown or visible in this picture: Judy Scharmann, Roger Oliva, Ram Gopel Gupta (India), Shunjun Wu (China), Zafar Taqvi (Galveston, TX), Jim Howard (for Jim Lumia–FL West Coast), Luis Riesco (Coastal NJ), and Iram Weinstein.

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**Table 1.**

**Pre-Summit Topic Assignments for Applying Aerospace Technologies to Current Issues Using Systems Engineering Techniques**

| Team I | Lead | Team II | Lead |
|---|---|---|---|
| **Group I-A** | | **Group II-A** | |
| Cyber-crime Detection and Enforcement | Alexander Pasmurov | FAA's NextGen Air Traffic Control | Luis A. Riesco |
| Biometrics | Chandra Gupta | Solving Future Space Debris Problem Today | Erik Blasch |
| High Schools' 9-year Focus | Andrew Piotrowski | Biosystems Engineering—Personalized Medicine | Mark Gober |
| **Group I-B** | | **Group II-B** | |
| Alternative Energy on the Smart Grid | Ali Nabavi | Special Material Detectors | Ram Gupta |
| Aging Aircraft and Obsolete Avionics | Ken Bandelier | Counter-IEDs | Murat Efe |
| High Speed Rail | Krzysztof Kulpa | Turning Physics into Quantum Computing | Oh Eun |
| Improved Transportation Efficiencies | Felix Yanovsky | System Integrity and Program Risk in Space Investments | Reza Dizaji |
| **Group I-C** | | **Group II-C** | |
| Leap-Frog the Social Net Technologies | Firooz Sadjadi | How to Control Climate Change | Fotini-Niovi Pavlidou |
| Assure Privacy-Intellectual Property Security | | Future Deforestation/Firefighting Methods | Stephane KemKemian |
| Transmission Bandwidth Solutions | Shunjun Wu | Agriculture Support Surveillance | Rick Tuggle |
| Assure Privacy and Intellectual Property Security for Medical and Other Personnel | Hugh Griffiths | Counter the Threat of a Near-Earth Object | Tyler Marshall |
| Aerospace Apps for Ocean Resource R&D | Michael Orlovsky | | |
| **Group I-D** | | **Group II-D** | |
| Next Gen Search & Rescue | Konstyantyn V. Ilenko | Aerospace to Solve Nuclear Power Safety | Vince Socci |
| Interdiction | Kathleen Kramer | Efficient Urban Utilities and Transportation Infrastructure Refurbishment | Abel Alim |
| Pre-solve Deep Sea Horizon-Type Events | Eli Brookner | Pre-positioned and Planned Weapons of Mass Destruction (WMD) Response | Young Kil Kwag |
| Manned Space Mission Capabilities | Khalid Tahir | Universities' 5-Year Focus? | Zafar Taqvi |

**All material from the AESS Chapter Summit event is posted at http://www.ieee-aess.org/documents/membership/chapter-activities/2011-chapter-summit.**

After the initial assignment, each AESS Chapter chair followed the established systems engineering evaluation analysis of their associated topic. Systems engineering [1] is an established field of engineering to manage complex systems, and numerous texts are available from the International Council on Systems Engineering (INCOSE) [2]. The original idea was to have Chapter Chairs define goals, objectives, and assumptions and do an analysis of alternatives (AOA) [3], risk analysis [4], and rough-order-of-magnitude (ROM) costing. An example of hazardous waste disposal systems engineering analysis and solution set was made available to the team members during the pre-Summit phase.

## SYSTEMS ENGINEERING EXERCISE

The meeting goals were sent to the Chapter Chairs along with the agenda, topic list, and three Summit exercises:

- As designed, the first exercise would be 30 days and culminate at the Summit. The pre-Summit exercise would establish goals, objectives, capability gaps, associated challenges, and outline resource restrictions for each topic.
- The second exercise would occur at the Summit and would be the topic swap where the work accomplished by Team I during the pre-Summit would be reviewed by Team II and vice versa. During the second exercise, a risk analysis would be accomplished by the reviewing team.
- During the third exercise, ROM resource requirements would be postulated and conclusions/way forward drawn for each topic.

The AESS Board of Governors (BOG) requested that each Chapter Chair, or alternate, review the topics and volunteer to lead one of the groups. The summit organization amounts to two team leaders and eight group leaders (four for each team). The group leaders developed a baseline exercise analysis of the topic overviews. The AESS BOG provided general goals, objectives, and guidelines as starting points for underrepresented topic analyses.

The Guidelines we published were simply as follows.

## "GUIDELINES AND STEPS TO ASSURE A SUCCESSFUL SYSTEMS ENGINEERING EXERCISE"

Each summit participant selects a topic for evaluation using their knowledge, on-line resources, and subject matter expertise available from the extended AESS community. A preliminary list of "Pre-Summit Goals and Objectives Applying Aerospace Technologies to Current Issues Using Systems Engineering Techniques" for each topic shown in Table 1 was made available on the Aerospace and Electronic Systems Society website at: http://www.ieee-aess.org/documents/membership/chapter-activities/2011-chapter-summit. The objectives were refined by each topic leader as needed.

## EXERCISE IA—PRE-SUMMIT

Each topic leader should:

- Establish the Goal
- List Assumptions such as Technical, Time, or Resource Constraints
- Establish Measurable Objectives
- Identify Capability Gaps and Associated Challenges
- List Alternative Solutions for Each Objective
- Perform Metrics on the Various Solutions
- Recommend Solutions Based on Prioritization as Given by Weighted-Metrics

*Topic leaders* were requested to create a Microsoft™ PowerPoint briefing (< 20 slides) and /or a White Paper (< two pages) covering the above pre-Summit information and send to the group leaders.

*Group leaders* regularly assessed that each topic was progressing in a timely manner and that the topics, albeit different, follow a similar systems engineering construct and consistent presentation format for efficient delivery to the team leader at the Summit.

*Team Leaders* frequently assessed that each group submissions were prepared consistently across the presentations and organized the complete packages to the BOG for Internet posting, topic swaps, and Exercise II review.

## EXERCISE IB—TOPIC DISCUSSION

On the morning of the Summit, group members coordinated and refined each topic's analysis via break-out sessions.

## EXERCISE II—TOPIC SWAP

The work performed by Team I during the pre-Summit and Exercise I would be reviewed by Team II and vice versa (i.e., Group1A reviews Group2A topics). Exercise II performed a risk analysis review and documented concerns and contradictions to original recommendations.

**Figure 2.**
Third Chapter Summit Chairs listening to Exercise Presentations (left–right): Adel M. Alimi, Iram Weinsten, Young Kil Kwag, Jim Howard (IEEE-USA 2012 President), Roger Oliva, Andrew Piotrowkski, Vince Socci.

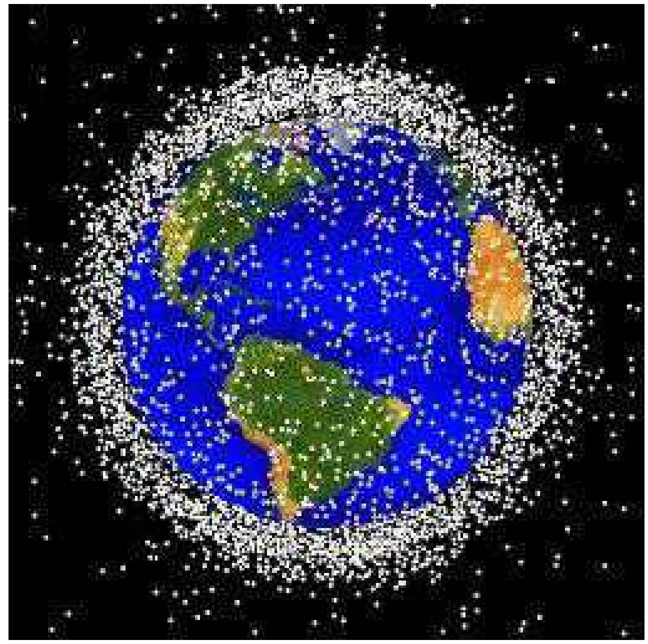

**Figure 3.**
Image of space debris from http://orbitaldebris.jsc.nasa.gov/photogallery/beehives.html.

## EXERCISE III—TOPIC SWAP-BACK

Groups' recommendations were passed back to original teams/groups for review and final analysis. The original group assigned a ROM cost and cost/benefit review for each recommendation under each topic. The goal of Exercise III was to capture conclusions for each topic and create an outbriefing as well as updating material for the presentation, shown in Figure 2.

## EXAMPLE—SOLVING THE SPACE DEBRIS PROBLEM

A systems engineering example includes an executive summary, background and goals, scenario and analysis, and recommendations. One example is how to solve (or monitor) the space debris problem.

## EXECUTIVE SUMMARY

Following common practice for tracking space debris, modeling shows that there is a need to upgrade facilities to focus on the debris detection for satellite safety and satellite-debris collision avoidance. There are alternatives on how to improve capabilities, such as build another distributed set of *sensors* for increased spatial/temporal detection, improve visualizations and *displays* for operator coordination and analysis, upgrade tracking and sensor management *algorithms* to extend continuous monitoring, and improve current *system exploitation* to discern small objects. We recommend a balanced approach across these areas with a focus on algorithm development (e.g., target exploitation) with the highest payoff at the least cost and risk.

## BACKGROUND AND GOALS

Space debris *modeling* and analysis includes many forms of space debris or "Space Junk" [5]. Figure 3 shows computer-generated images of currently *tracked* objects in Earth orbit. Approximately 95% of the objects in Figure 3 are orbital debris, i.e., not functional satellites. The orbital debris dots are scaled according to the image size of the graphic to optimize their visibility and are not scaled to Earth. The most concentrated region for orbital debris is low Earth orbit (LEO) (2,000 km above Earth's surface) [5].

The Space Surveillance Network (SSN) [6] currently tracks more than 8,000 space objects orbiting the Earth from 20 distributed radar and optical *sensor* sites. The space objects now orbiting Earth range from satellites weighing several tons to pieces of spent rocket bodies weighing only 10 pounds. About 7 percent of the space objects are operational satellites, the rest are debris [6]. Additional details on space debris modeling are available from the **National Aeronautics and Space Administration** (NASA) [7]. Future technologies for the SSN include visualization upgrades, algorithms to track detected objects, and consideration of advanced exploitation methods to discern small-sized debris.

Based on an estimated analysis of the current space debris problem, a brief analysis of stakeholders, goals, and objectives for space debris assessment include:

**Possible stakeholders include:**

- Satellite service providers (satellite protection for industry, defense, and social applications);
- Space use shareholders (NASA and the International Space Station);
- Community users sharing the communications and GPS products;

- Governments with defense and social (e.g., weather monitoring services) needs; and
- Indirect companies providing communication services from satellites.

**Goal:** Reduce the threat of damage to space platforms caused by space debris.

For a variety of stakeholders, there is a need to upgrade the knowledge of the space debris location, density, and movement. The solution supports the needs of the international industrial community (e.g., communication satellites), defense applications (e.g., International Space Station and surveillance satellites), and service providers (e.g., GPS satellites and weather satellites). However, the solution is also based on the integrated and restricted space tracking resources that afford a common coordinated effort.

**Possible objectives and alternatives include [8]:**

- Develop models to evaluate and improve space debris tracking;
- Provide resources to the SSN space debris tracking mission with international funding;
- Protect spacecraft with affordable shielding and maneuverability;
- Create an internationally funded commission with the responsibility of mitigating intentional debris;
- Fine launch providers when their event ends with uncontrolled debris adding space junk; or
- Hire space junk collectors for the most threatening space objects.

Thus, the goal of the summit exercise is to give a recommendation as to how to select among the alternatives for improved capabilities while minimizing the cost to application providers. From the background information, a notional scenario and analysis is conducted to determine the areas of concern for the next decade (*based only on the AESS Chapter Summit participants' opinions as per the exercise and the topic discussion and swaps*). It was determined that the above objectives and alternatives were grouped into three categories: technical, political, and economical/social. The specific interests of interest to AESS are the technical improvements.

## SCENARIO AND ANALYSIS

### Normative Scenario

Future options to upgrade space monitoring technology include four alternatives: (1) build another distributed ground-based and space-based (not considered [9], [10]) sensor for increased spatial detection, (2) improve display technology through visualization enhancements for operator coordination and analysis [11], (3) upgrade tracking and sensor management algorithms [12] with novel methods for improved debris location accuracy and prediction for space situational awareness, and/or (4) improve exploitation capabilities for detection, modeling, and analysis of small-sized space debris. The scenario-based analysis [13] includes determining which of the above methods has the largest benefit over the information fusion quality of service metrics of timeliness, accuracy, confidence, throughput, and cost [14]. However, the cost (or profit) is not considered as the protection and maintenance of space satellites is important but cost-distributed among many stakeholders.

### Assumptions

A few key factors that were not included in the analysis are cost of sensors (reduction in costs included as only system upgrades), sharing of collection data, modeling of space-atmospheric conditions, expected impact/threat of a satellite-control accident, and country-specific responsibility of debris control. The focus was on increased monitoring (detection) of space debris using existing resources and the increased capability with available technical improvements.

Four components of sensors, displays, tracking algorithms, and exploitation systems were defined as possible technical improvement categories each with an allocation cost. Using the SSN, there are 20 existing sensors, and an additional sensor, well placed, can increase the spatial coverage at a high cost. The display technology would enable operators to better interact with the system, while tracking algorithms would monitor the debris location to alert for possible collisions. The exploitation capability would focus on the sensor design and processing to improve small-sized debris detection. To compare methods, these options created independent alternatives and the metrics are weighted based on cost contributions.

A ***balanced approach*** would enable tracking space debris, but some choices to consider are:

- Build a new ***sensor(s),*** which requires more cost, is application dependent, and requires coordination with the SSN [6];
- Upgrade ***display*** capabilities for Space Situational Awareness (SSA) [15]–[17], which improves analysis over all debris and satellite locations with existing detection capabilities;
- Enhance sensor management and target-tracking ***algorithms*** to control existing sensors to observe targets and reduce covariance updates [18]; however, it requires application-dependent control of sensors; and
- Improve ***detection*** methods for targeting using all distributed existing sensor observations to associate small tracks, increase the throughput of number of targets detected, and extend track lifetime of locations of targets.

To conduct an analysis of alternatives (AOA), the benefit/cost impact of the objective choices above were weighted as to the impact on the quality of service (QOS) metrics [19].

**Table 2.**

| Percentage of Allocation Costs to Meet Measures of Performance (MOPs) | | | | |
|---|---|---|---|---|
| | **Sensors** | **Displays** | **Track Algorithms** | **Detection** |
| Timeliness | 0.6 | 0.1 | 0.1 | 0.2 |
| Confidence | 0.2 | 0.1 | 0.3 | 0.4 |
| Accuracy | 0.2 | 0.1 | 0.4 | 0.3 |
| Throughput | 0.2 | 0.0 | 0.3 | 0.5 |

Table 2 details the contribution of each method (column) to the QOS metric (row).

For the risk analysis, the objective choices for algorithms and software changes pose limited risk. To quantify the risk associated with the new sensor could involve environmental and economic concerns depending on the location of the sensor. However, adequately describing the risk is minimal compared to not doing anything to improve technology to monitor the space debris [9].

Assuming that the allocation of costs (using an independence assumption) for each method is implied, a ROM weighted cost factor was applied to each method where the cost relation is {sensors > detection > track algorithms > displays}. While it is difficult to determine the actual costs, it is assumed that the cost for designing hardware (e.g., a sensor) is significantly larger than software (e.g., tracking, detection, and displays). Figure 4 presents a spider chart of the four choices including relative MOPs and their systems level impact toward a measure of effectiveness (MOE). Notionally, the larger the bounded area in the plot implies an improved MOE (without scaling), which assumes that cost could be compared (e.g., inversely proportional).

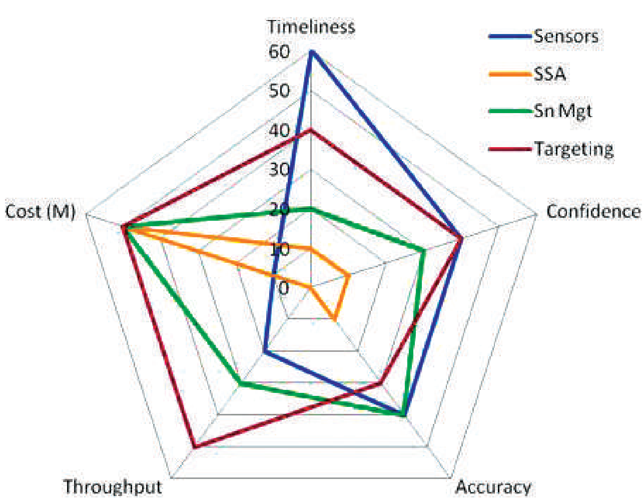


**Figure 4.**
Method comparisons using a measure of effectiveness plot.

From Figure 4, building a new *sensor* has a large MOE, but would cost more than other "method" improvements. Moving clockwise from cost, the next MOP is timeliness. The extra sensor also improves timeliness as more sensors lead to improved sampling. Timeliness is also important to *SSA* and *sensor management (SnMgt)* [20], but is not as significant as *targeting,* which identifies the debris over position updates. Confidence in debris detection and location accuracy improves for sensors, sensor management and tracking algorithms, and targeting exploitation; however, SSA remains about the same as it is focused on the display of current detections. The last MOP is throughput, which here is defined as the number of small objects tracked. Exploitation targeting improves detection and hence the tracklife (same target for longer time periods). From the AOA, ROM, and a quick look at the MOE plot, increasing target exploitation (and hence debris detection) would be a recommended choice.

### Recommendations

Based on the limited analysis, AOA, and ROM costing, many different options can be determined, but a balanced approach is needed across the objective solutions for an effective strategy. Space-debris tracking is international problem affecting economic, social, and infrastructure applications. To further mitigate the risks of damage to space platforms caused by space debris, focus should be coordinated over new distributed sensors, sensor management and tracking algorithms [21], and SSA display and detection technology [22], with an expected larger benefit/cost ratio for target exploitation methods to categorize the space debris and support the other objectives.

## DISCUSSION

Anyone with experience with these types of activities will tell you that 500+ e-messages should be expected over the numerous topics in Table 1. Sure enough, from start to finish, the number of e-trails created for this exercise numbered about 450 through the exercise coordinator. The peak numbers occurred the week before the Summit, of which Exercise IA was coordinated for consistent analysis.

There are statistics and lessons learned that can be drawn from the evolution of the topic evaluation process. For the three weeks prior to the Summit, one of the key elements to note is that final products were clearly reflective of the time put in by the topic leaders. Another more important key element was that the AESS is a volunteer organization, and there is no way to compel people to work in areas that challenge their knowledge base. Through gentle encouragement, reminders, and what we hoped were timely answers to process technical questions, the four groups per team and two teams were formed. What we had, many believed, was a noble pursuit that would energize the topic leaders to provide topic presentations for Exercises 1 through III during the Chapter Summit.

During the week before the Summit, 65 percent of the topic leaders were confirmed, and Exercise IA was progressing. Many presentations were superb and passed to subject matter experts for review. The week of the Summit, 25 of the 30 topics were on their way to being completed. Cursory analysis and placeholders were created for the remaining five topics, and the group leaders were on-board with their duties for this pre-Summit exercise as part of Exercise I. Given that most Chapter Chair Representatives knew no one in their groups much less on their teams, Team Leaders were not selected until we all met at the Summit.

On the morning of the Summit, the AESS BOG members presented the business aspects of the Summit. To kickoff the Summit Exercise, a Presentation and Discussion were delivered to outline the Systems Engineering strategy.

The Summit Exercises were “refined” in-process. Exercise I progressed for more than an hour, and the eight groups were fully engaged in assessing and refining their topics. The challenge posed to each group was to show how they would spend a hypothetical $5 billion allocated to each topic. Some topics would be zeroed out, if that was what the group believed to be the right answer. Redistribution of the resources available to the group’s topics was not bounded to the individual topics. Outputs from Exercise I were superb. Objectives, analysis of alternatives, and reasonable ROM resourcing was set forth by each group and summaries provided to Team Leaders. Exercise II was a topic swap where new groups were formed to evaluate other’s topics, and refinements were made to the original guidelines.

The development of the Exercise II topics fared more uncertainly. We simply did not know how well new groups could or would defend their new topics given that in most cases the topics were outside of their field of expertise. Lack of familiarity with new group members slowed this process as expertise and coordination were needed to understand the new topics. Also, we skipped over the Team I and Team II overarching reviews due to a relatively slow submission of a few group summaries after Exercise I. If these two Team reviews of Exercise I would have been done as scheduled and before thrusting into Exercise II, everyone would have had a clearer picture of the overarching goals. Groups in Exercise II also would have had a better understanding of topics that they otherwise had little knowledge. A successful Exercise II would have served to refine and give cohesiveness to the end-products and would have positioned a smooth transition to Exercise III.

Fortunately, these issues were projected, and the key aspects of Exercise III were handled during the relatively slow development of Exercise II.

Regarding the Systems Engineering exercise, it was a great success. The interaction and development of these different topics and respective groups showed the significant value of concurrent engineering principles [23], [24]. With the right approach, these topics could easily be taken to the next level for prioritization of the emerging areas for AESS. That is, real program development activities could and probably should be pursued with systems of systems concept [25]. Work put in by our Chapter Representatives benefited all attendees, as we expected.

## CONCLUSIONS

The Summit Exercise was a success because it brought together more than 40 knowledgeable engineers and their thought-provoking work on 30 current engineering topics, and it demonstrated good systems engineering and collaboration. The Exercise resulted in reasonable prioritizations, technical recommendations, and breadth of knowledge expansion for most people on the related topics. The power behind this activity remains available to anyone that takes the time to review the individual presentations and participate in the Exercise. The key aspects for IEEE AESS include the topic selections, the Exercise development, and the summary debriefings from the participants. The SE methodology could be utilized by AESS Chapters as a useful exercise in member introductions, idea generation, and appreciation of IEEE engineering challenges (as demonstrated in the AESS Washington, DC/Northern Virginia Chapters). There would be a benefit to IEEE AESS if these existing and additional topics were further vetted, to a more complete solution, and direct relations to the AESS readers who develop systems in many IEEE areas. ❖

## ACKNOWLEDGMENTS

Special thanks again go out to the AESS BOG for permitting the creation of the AESS Systems Engineering exercise. We can speak for the vast majority of the participants by expressing our appreciation for the encouragement given to enable this venue to move forward through obstacles, provide a forum for AESS Chapter introductions, and analysis of topics pertinent to AESS Chapters. The creation of a System Engineering Panel is now being considered by the AESS BOG.

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