4th Asia-Pacific Conference on Systems Engineering (APCOSE 2010)
Keelung, Taiwan October 4-6, 2010

How synergy between amateur radio, systems and other engineering can raise the technical quotient of a nation

Joseph Kasser, CM, CEng, CMALT (9V1CZ, G3ZCZ and VK5WU)
Visiting Associate Professor
Temasek Defence Systems Institute
National University of Singapore
Block E1, #05-05, 1 Engineering Drive 2, Singapore 117576
Telephone +65 6516 4604, Fax +65 6778 9656
Email joseph.kasser@incose.org

ABSTRACT

Radio amateurs provide a pool of technically competent personnel that contribute to information engineering and communications and other technical professions in countries in which it is an established hobby; countries such as Japan and the USA. In the Asia-Pacific region, while Japan has more radio amateurs than any other country, governments of the lesser developed countries tend to ignore amateur radio as a source of the indigenous personnel needed to help provide the benefits of 21st century technology. This paper first addresses the problem of educating good systems engineers by suggesting that potential students be preselected from pools of candidates who show characteristics deemed desirable in systems engineers. The paper then shows that one source of partially trained personnel maybe found among the technical members of the amateur radio community and similar technical hobbies. The paper then discusses some of the technical achievements of amateur radio followed by the twelve engineering roles of amateur radio in the manner of (Sheard 1996) and proposes that there is enough similarity between amateur radio's technical activities and the role of systems engineering so that amateur radio can provide a source for students with experience in systems engineering activities. The last section of the paper then mentions some amateur radio failures that systems engineering should have prevented and concludes with a discussion on recruiting young systems engineers via amateur radio clubs, some synergy between INCOSE and amateur radio clubs and suggestions for future research.

KEYWORDS: systems engineering, amateur radio, engineering education.

1. INTRODUCTION

The world is turning to systems engineering to help acquire and maintain the complex systems that underpin our 21st century civilization. As a consequence, demand for skilled, knowledgeable, systems engineers in government, industry, and academia is increasing around the world [1]. This demand is placing pressure on academia to produce systems engineers; pressure to which academia is responding by developing new content and more effective ways of delivering courses [2-4] and degrees [5, 6] [7, 8]. Even with the focus on content and pedagogy the courses still suffer from drop outs and can still produce graduates who do not have the characteristics of systems engineers [9].

2. THE DESIRABLE CHARACTERISTICS OF A SYSTEMS ENGINEER

The literature contains a wealth of information about the desirable characteristics of a systems engineer e.g. [10, 11], so exercises could be designed to practice those skills. However, many courses in systems engineering focus on the knowledge component and leave the providing of the skills component to the individual instructor with varying results.

One of the earliest articles on the skills of systems engineers was Hall [10] who provided the following specifications or traits for an "ideal

systems engineer".

- **An ability to see the big picture** - the most important trait. It means that the systems engineer is not concerned primarily with the devices that make up systems, but with the concept of the systems as a whole - its internal relations and its behaviour in the given environment (systems thinking).
- **Objectivity** - the ability of appraisal with complete objectivity.
- **Creativity** - imagination is very necessary.
- **Human Relations** - not just the ability to get along with people, but the positive attributes of leadership, tact, diplomacy and helpful concern, so essential in effective teamwork.
- **A Broker of Information** - the gift of expression - oral, written, and sometimes graphic.
- **Education** - Graduate training in the relevant field of interest (application), as well as courses in probability and statistics, philosophy, economics, psychology, and language.
- **Experience** - Experience in research, development, systems engineering and operations.

Later studies include [12] and [13] who consolidated and classified the characteristics of successful systems engineers into ten cognitive characteristics, eleven abilities, ten behavioral competences and fifteen dealing with knowledge. Prior research by Kasser et al. [4] stated that characteristics employers of systems engineers were looking for included:

- Competent, skilled and knowledgeable systems engineers capable of effectively working on various types of complex integrated multi-disciplinary systems in different application domains, in different portions of the system lifecycle, in teams, alone, and with cognizant personnel in application and tool domains.
- Engineers who are effective at solving open-ended problems [14].

3. FINDING SUITABLE SCREENING CRITERIA

If academia could find the ability to identify potential systems engineers who may have some pertinent characteristics and experience prior to their commencing coursework, the degree program in systems engineering would turn out more effective systems engineers and the drop-out rate from the course should fall. The problem is the development of screening or pre-selection criteria for admitting students into the degree program.

The capability for engineering system thinking (CEST) is a proposed set of high order thinking skills that enable individuals to successfully perform systems engineering tasks [13, 15]. CEST, developed based on a survey of what people in Israel thought were characteristics of successful systems engineers, identified fourteen cognitive characteristics, twelve capabilities, nine behavioural competences and three knowledge and experience characteristics (38 characteristics in total). The research hypothesized that successful systems engineers could be characterized by high levels of CEST. However CEST is still in an early stage and is proposing future research to use CEST as a basis for psychological testing to assess a person's interest for systems engineering positions and other engineering positions that require systems thinking with a goal of identifying those individuals that have a greater probability of becoming successful systems engineers. The promise of CEST is unknown, so an alternative approach should be identified.

From the generic systems thinking perspective [16] if another activity that shares the competencies and skills of the systems engineer could be found, then selecting students from people who are performing that activity should provide students with a higher probability of graduating the systems engineering course with high grades and then going on to becoming successful systems engineers in industry and government. This paper now proposes that amateur radio, a hobby that encompasses the development and operation of socio-technical communications systems is one such activity[1]. Amateur radio has existed since the time of Marconi, Hertz and others began their experiments. It is the only hobby regulated by the government of every country in the world. To obtain their operating licenses, amateurs are

[1] Other technically inclined hobbies might also be considered as potential sources of systems engineering candidates.

Table 1 Numbers of Amateur Radio operators in selected Asia-Pacific countries

Country	Number of amateur radio operators	Year of Report	Source
Japan	1,296,059	1999	IARU
United States	733,748	2010	FCC
Thailand	141,241	1999	IARU
South Korea	141,000	2000	IARU
Republic of China	68,692	1999	IARU
People's Republic of China	20,000	2008	CRSA

required to pass a written examination in radio regulations and fundamentals of radio technology. More than a 1.5 million persons worldwide are licensed amateurs. The majority of amateur radio operators worldwide reside in Japan, the United States, Thailand, and South Korea in the Asia-Pacific region as well as in the nations of Europe. Although the numbers in some counties are somewhat dated, Table 1 does provide an indication of the size of the potential pool of candidates.

Radio amateurs have applied systems engineering principles and made many important contributions to the state-of-the-art in telecommunications. For example, they:

- Discovered and pioneered the long distance communications potential of short waves in the early years of the 20th century.
- Pioneered many of the techniques now used for the vhf/uhf personal communications services.
- Constructed and communicated via the world's first multiple access communications satellite (OSCAR 3) in 1965.
- Pioneered the Emergency Locator Transmitter (ELT) System now used to locate downed aircraft via AMSAT-OSCAR 6 in the mid 1970's.
- Often provide communications capabilities for the public services immediately following a natural disaster or other event which wipes out commercial communications into or out of the disaster zone.

These days amateur radio is a hobby that covers a broad range of activities. It even has its own annual international conferences and technical symposia. Amateur radio technical symposia contain presentations of the same quality as professional events organized by INCOSE Chapters. For example, the Wireless Institute of Australia held a one day seminar in Adelaide on October 2, 2004. Topics incorporating systems engineering techniques discussed by the speakers included, communicating by bouncing radio signals off the moon [17] and communications using vhf radio signals reflected off meteorite ionization trails in the ionosphere [18].

Radio amateurs can be classified into two groups, communicators and technical. The communicators use amateur radio to talk over radio frequencies. The technical radio amateurs develop systems that range from the simple to the complicated. Individual technical radio amateurs set up amateur radio stations in various locations, fixed, mobile, and even in outer space [19, 20] in amateur built spacecraft [21], the Soviet Mir Space Station [22] and on the International Space Station.

Educational institutions are constructing small spacecraft which do get launched as educational satellites. Examples include descriptions in [23, 24] and the micro satellites developed at the US Naval Academy in Annapolis, MD. The skills the students learn during the development of these spacecraft include many of the skills needed by a systems engineer. However, the number of such programs is small and opportunities are limited. Amateur radio however does have the potential to develop a systems engineering attitude among the minority of amateur radio operators who are also experimentally minded. This minority of more than 1.5 million people is still a substantial number of potential systems engineers.

Each amateur radio installation tends to contain antennas, radios, accessories, and computers, namely each installation can be considered as a system. Each installation can also be considered as part of a networked system of communications nodes, the range and traffic handling capabilities of the network depending on the radio frequency. These radio networks have been linked to the Internet to provide additional functionality. These radio amateurs are involved in more than communicating; they experiment with new technologies, some of which are then

adopted by the professionals [25]. The scope of this paper is limited to those technical radio amateurs.

4. COMPARING THE ROLES OF THE SYSTEMS ENGINEER TO THE ROLES OF THE TECHNICAL RADIO AMATEUR

If the word "systems engineers" in the traits for an ideal systems engineer provided by [10] is changed to "technical radio amateur", the traits would be just as applicable with the additional change that the education requirement would not be at the postgraduate level. In addition, consider that radio amateurs in general do not have the resources that the professionals have; hence they must exhibit a great degree of resourcefulness and creativity. So consider each of the twelve systems engineering roles [26] and how those roles map into amateur radio.

1. Requirements owner. Radio amateurs translate customer needs to technical requirements. They are their own customers much of the time, since they are purchasing or constructing equipment for their own stations. However, in clubs and technical societies, or when creating emergency response communication systems they translate needs of the group into technical requirements. To ensure that requirements are feasible, they need to understand the nature of the requirements, equipment, interfaces (human and electronic), and the propagation characteristics of the radio frequency and other elements (network nodes etc.) used to transfer messages between stations. In technically advanced groups such as the Radio Amateur Satellite Corporation (AMSAT) who design area-wide communications systems and communications satellites, an understanding of the needs of the users is a fundamental competence.

2. System designer. Once the requirements are known, the systems must be designed. Often the choice is between which commercial off the shelf (COTS) products to incorporate in the design. Sometimes, if individuals have technical competences they may design systems based on copying or modifying designs published in professional or amateur radio technical publications or design their own. Other times the choice may be to buy parts of the system and construct others. Interface management is an important activity in ensuring that the components of the communications system work together to provide the required functionality. Radio amateurs face 'system of systems' problems all the time integrating somewhat compatible COTS products from different vendors into a working system. Problems may be resolved in simple ways by plug and socket adapters or by designing and constructing interface hardware and software components.

3 Systems analysts. The systems analyst role confirms that the system will meet requirements. For the average amateur station this role is performed by comparing the specifications of COTS products to the needs of the individuals. However, when the designs of remote or emergency equipment or even spacecraft are being analyzed, the analysis covers diverse characteristics such as weight, power, throughput, output, reliability, etc. A wide range of software tools have been developed for modeling and simulation in a similar manner to those tools developed for systems engineering. These tools can be used to model and simulate antennas, radio propagation at various frequencies, and circuits which provide various degrees of functionality. A number of commercial tools and products began life serving the radio amateur market.

4. Validation and verification. Radio amateurs plan and implement tests of systems. To do this properly they must understand what they are testing, and how to tell when the system passes or fails the test. Sometimes these tests involve other people. Hence they must be scheduled at appropriate times. Test equipment must be affordable and have sufficient accuracy and sensitivity, which is not always easy on an amateur budget.

5. Logistics and operations. This is the role of logistics, maintenance and disposal. Sheard defines this role in systems engineering as the back end of the system life cycle where the knowledge of how the equipment is being used is important, and the equipment needs to be maintained. Systems engineers, in general, have

only recently recognized the need to deal with the problems posed by the extension of operational lifetimes of equipment to time frames well beyond those originally envisioned by the acquirers and designers of the original systems. While many radio amateurs want to use the latest and greatest equipment, there are many others who on the other hand, tend to operate equipment for as long as they can (for financial reasons), and a small group who delight in repairing and maintaining vintage equipment. When older technology vanishes from the supply chain (retail and surplus stores), they pursue spare parts in dedicated amateur radio flea markets and car boot sales, known as hamfests, swapfests or swap'n shops, the largest of which takes place annually in Dayton Ohio in the USA in the month of April. The professional faced with the problem of supporting irreplaceable software running on obsolete vintage computers for which hardware spare parts are lacking might look to the annual Dayton Ham convention as a source for otherwise unobtainable parts.

6. Glue. This is role of troubleshooter who looks for and solves problems. Since radio amateur systems tend to be assembled in an ad-hoc manner from various sources and evolve over periods of time[2], radio amateurs need to be adept at what has become known as systems of systems thinking. Since many problems occur at interfaces, and given the nature of the different manufacturers of the components of the system, the radio amateur develops a sense for identifying and solving interface problems. Sheard puts this role as ensuring that the system does not do what it is not supposed to do and cites electromagnetic compatibility as one of the areas the Glue system engineer has to handle. Radio amateurs now have to deal with homes that are becoming ever more electronic and have to deal with preventing interference not only to the traditional broadcast radio and television sets, but to a whole range of electronic equipment found in the home such as audio equipment, home entertainment centers and personal computers.

7. Customer interface. Radio amateurs perform this role in several ways. Often the problem of electromagnetic interference manifests itself in the neighbor's home whereupon the radio amateur has to meet the needs of both his neighbor and himself. As a second example, in clubs when projects are initiated in which a group of members construct equipment, one member tends to handle the purchasing for the group and becomes the customer interface.

8. Technical manager. This role includes controlling costs and scheduling resources. As an example, radio amateurs take on this role in various ways; the most common opportunity for technical management being raising antennas. Some amateurs own towers in their back yards that can be 60 to 70 feet high. Raising such a tower and installing the antennas at the top is no trivial task. It has to be planned, scheduled and controlled. Sometime permission has to be obtained from the local authorities. The logistics have to be correct so that all parts and personnel are where they are supposed to be when they are supposed to be.

9. Information manager. The radio amateur manages information all the time. Historically there has been a requirement to keep a record or logbook of transmissions and stations contacted. This is an obvious database application. Since there are a plethora of awards available from different organizations for contacting other stations of various types, those members of the fraternity interested in awards use databases, and their numbers are large enough to support a cottage industry of software developers for specific database applications.

10. Process engineer. This role calls for defining and capturing systems engineering metrics and much more [27]. Measurement is a part of the hobby of amateur radio. Some measurements are required under the terms of their license (e.g. knowledge of their transmitting frequency and radiated output power). Measurements range from simple lengths of antennas, to frequency and variations in frequency due to a number of effects (changes in ambient temperature, voltage, etc.). Some amateurs measure, collect statistics and analyze more complex data such as radio propagation conditions and network traffic.

[2] One of the definitions of a system of systems.

11. Coordinator. This role requires knowledge of several disciplines, leadership skills and the ability to facilitate groups in developing their own systems engineering skills. Radio amateurs perform much the same function, they actively encourage others to become radio amateurs and set up training classes in local clubs. They often take part in club activities in which groups of radio amateurs work together to meet a specific goal, such as setting up a field day system. Other examples of coordination include arranging contacts by bouncing signals off meteor trails in the ionosphere, bouncing signals off the moon, and remote control of amateur radio stations via the Internet. Getting everybody to work together in harmony when there are no official lines of authority is no mean feat! An understanding of motivation and leadership is a critical skill they develop in this role.

12. Classified Ads systems engineering. This role encompasses the other aspects of systems engineering. There are many other aspects of amateur radio that have not been discussed herein [28] that map into the [29] elements of systems engineering.

5. DISCUSSION

The roles discussed above constitute both top-down and bottom-up systems engineering in Layers 1, 2 and 3 and columns A – G in the Hitchins-Kasser-Massie Framework (HKMF) for understanding systems engineering [30]. By addressing the types of problems faced in determining needs, designing interfaces for families of products (produced by various manufacturers in different countries) that are constantly evolving these people build up valuable applicable experience for their future career in systems engineering and information technology. In addition, unlike professional systems engineers, most of these people work in a resource limited situation often trading time for money. They are often forced to innovate and generally have to design from inventory making use of commercial-off-the-shelf (COTS) components and (upgrade) existing capability

Radio amateur projects can also benefit from systems engineering. The entire amateur radio satellite program went well when systems engineering approaches were used. However, there were situations when systems engineering was ignored or poorly implemented (matching the professional world) with similar undesirable outcomes. Consider the following examples:

- **Small satellite telemetry.** Radio amateurs and universities have build and orbited small satellites. Each group designs and builds both the space and ground systems using limited resources. While some hardware concepts are copied in each generation, the concepts of reusable software and telemetry format standardization do not seem to have been adopted; each group designs their own telemetry downlink formats. The idea of such a standard and its advantages based on professional telemetry and data storage techniques was published in a professional conference as long ago as 1992 [31]. The use of such standards would relieve the design team from developing functionality that already exists and allow them to focus their limited resources on developing new mission related functionality.
- **Low earth orbiting satellite message store and forward capability.** In the early 1980's AMSAT designed and orbited a number of satellites that carried data storage and forwarding capabilities. Instead of modifying then existing terrestrial message store and forward software a new set of protocols were published. This resulted in dedicated volunteers spending up to two years writing software that duplicated the functionality of (well debugged) software already in existence.

Packet radio messaging network. When radio amateurs adopted modified landline packet radio protocols for use on radio circuits they used an incremental (non systems engineering) approach. Instead of utilizing the characteristics of the amateur data network with its hidden nodes and stations that were only operational some of the time, the focus was on developing a central station and servers similar to the wired network, namely an amateur version of the then budding Internet. As a result the system suffered (unnecessarily) from hidden node interference and unnecessary outages when the central servers occasionally went offline. An alternative system concept that allowed messages to be stored and retried on any system in the network by another other station was not explored. Consequently,

when the Internet became cheap the radio amateur packet radio messaging network became a fond memory (except for one or two specific applications). In another instance of the system development, as part of packet radio message store and forward capability, country destination codes were needed to identify the location of message recipients. The country codes associated with the international telecommunications networks were adopted. This meant that radio amateurs also active on short wave communications had to learn two sets of country identifiers; the existing prefixes used for call signs and the international telecommunications suffixes now seem on many Internet URLs.

Since technically oriented radio amateurs posses experience in the roles of the systems engineer, the drop out rate in post graduate classes should be lower because these students will have anchor points to relate the systems engineering knowledge being taught in the classroom to their prior experience.

In addition, as well as becoming systems engineers, technically oriented radio amateurs have in the past also become engineers, and military communications specialists. Amateur radio is fun and may also be a way to counter the current decline of interest in science and engineering education.

6. RECRUITING POTENTIAL SYSTEMS ENGINEERING STUDENTS

Recruiting technically oriented radio amateurs for systems engineering has to incorporate both marketing and selling. Marketing can be done using outreach techniques by systems engineering departments to university amateur radio clubs and by INCOSE chapters in the form of joint events between the chapter and a local amateur radio club. These clubs tend to have the same problem finding speakers as do INCOSE chapters. Providing speakers at each other's meetings would be an interesting way of solving the program chair's problem in finding speakers and provide interesting meetings that could lead to further cooperation as well as potential systems engineers.

INCOSE working groups provide individual opportunities to work in aspects of systems engineering other than those of the daily job and expand one's skills, competence and knowledge. Sometimes useful projects are hard to locate. However, by working with radio amateur organisations in their own areas projects could be found. Some amateur radio projects are complex. For example, New Zealand, and some large area of the USA have vhf and uhf amateur radio communications links over wide areas provided by linked communications systems. Systems engineers could help design and test these systems and become role models for young radio amateurs.

7. FURTHER RESEARCH

In the 20th century amateur radio provided a stepping stone to careers in communications and information technology. Amateur radio has the potential to provide a similar stepping stone to careers in systems engineering in the 21st century. Many notable professionals in the information technology fields are radio amateurs, some are even systems engineers. It would be worth surveying them to determine the contribution of their hobby in their formative years to their excellence in their fields.

It would also be interesting to submit a sample of the technical and experimental subset of radio amateurs to CEST testing and determine if there is a correlation.

8. SUMMARY

This paper has argued that preselecting students showing characteristics deemed desirable in systems engineers can improve the quality of systems engineering graduates produced by university courses in systems engineering and reduce the dropout rate in courses. The paper has also shown that the characteristics of technical radio amateurs are similar to those of system engineers and suggested that amateur radio be considered as one of several pools of potential recruits for university level systems engineering courses.

9. CONCLUSION

Amateur radio is one hobby that may provide a source of systems engineers. The author invites readers to identify others from their experience and write about them. We need all the good

systems engineers we can get

10. AUTHOR

Joseph Kasser combines knowledge of systems engineering, technology, management and educational pedagogy. Having been a practicing systems engineer and engineering manager since 1970 in the USA, Israel, and Australia he brought a wealth of experience and a unique perspective to academia in 1997. He has since become internationally recognised as one of the top systems engineering academics in the world. He is an INCOSE Fellow, the author of “A Framework for Understanding Systems Engineering”, “Applying Total Quality Management to Systems Engineering” and many INCOSE symposia papers. He is a recipient of NASA’s Manned Space Flight Awareness Award (Silver Snoopy) for quality and technical excellence for performing and directing systems engineering and the recipient of many other awards, plaques and letters of commendation and appreciation. He holds a Doctor of Science in Engineering Management from The George Washington University, is a Certified Manager and a certified member of the Association for Learning Technology. He gave up his positions as a Deputy Director and DSTO Associate Research Professor at the Systems Engineering and Evaluation Centre at the University of South Australia in early 2007 to move back to the UK to develop the world’s first immersion course in systems engineering as a Leverhulme Visiting Professor at Cranfield University. He is an INCOSE Ambassador and also served as the initial president of INCOSE Australia and as a Region VI Representative to the INCOSE Member Board. He is currently a Visiting Associate Professor at the National University of Singapore and a principal at the Right Requirement Ltd. in the UK.

He has been a radio amateur for longer than he has been a systems engineer. He spent 15 years as the editor of the flagship publications of the AMSAT attributes much of his expertise as a systems engineer to his amateur radio interest.

11. REFERENCES

[1] E. P. Arnold, "Defining, Finding, and Hiring REAL Systems Engineers," presented at 16th Annual Symposium of the International Council on Systems Engineering, Orlando FL, 2006.

[2] J. E. Kasser, "Developing the Requirements for Introductory Courseware for Systems Engineering," presented at the Asia Pacific Systems Engineering Conference, Singapore, 2007.

[3] J. E. Kasser, "Improving undergraduate education in systems engineering," presented at INCOSE Taiwan 2006 Conference on Systems Engineering and Management,, Taichung, 2006.

[4] J. E. Kasser, P. John, K. Tipping, and L. W. Yeoh, "Systems engineering a 21st century introductory course on systems engineering: the Seraswati Project," presented at the 2nd Asia Pacific Conference on Systems Engineering, Yokohama, Japan, 2008.

[5] J. E. Kasser, S. C. Cook, D. R. Larden, M. Daley, and P. Sullivan, "Crafting a Postgraduate Degree for Industry and Government," presented at International Engineering Management Conference, Singapore, 2004.

[6] J. E. Kasser, E. Sitnikova, X.-L. Tran, and G. Yates, "Optimising the Content and Delivery of Postgraduate Education in Engineering Management for Government and Industry," presented at the International Engineering Management Conference (IEMC), St. John's, Newfoundland, Canada, 2005.

[7] R. Valerdi, R. Jain, T. Ferris, and J. E. Kasser, "An Exploration of Matching Teaching to the Learning Styles of Systems Engineering Graduate Students," presented at the 19th International Symposium of the International Council on Systems Engineering, Singapore, 2009.

[8] R. Jain and D. Verma, "Proposing a Framework for a Reference Curriculum for a Graduate Program in Systems Engineering," The International Council on Systems Engineering 12 February 2007 2007.

[9] S. Hudson, "Systems Engineering Competencies Framework," INCOSE UK Issue 2, November 2006 2006.

[10] A. D. Hall, *A Methodology for Systems Engineering*. Princeton, NJ: D. Van Nostrand Company Inc., 1962.

[11] M. Frank, "Assessing Interest for Systems Engineering Job Positions - Results of a Recent Study," presented at Conference on Systems Engineering Research, Hoboken, New Jersey, 2007.

[12] M. Frank, "Characteristics of Engineering Systems Thinking: A 3-D Approach for Curriculum Content," *IEEE Transaction on Systems, Man, and Cybernetics, Part C*, vol. 32, no. 3, pp. 203-214, 2002.

[13] M. Frank, "Knowledge, Abilities, Cognitive Characteristics and Behavioral Competences of Engineers with High Capacity for Engineering Systems Thinking (CEST)," *The INCOSE Journal of Systems Engineering*, vol. 9, no. 2, pp. 91-103, 2006.

[14] Durward K. Sobek II and V. K. Jain, "The Engineering Problem-Solving Process: Good for Students?," presented at 2004 American Society for Engineering Education Annual Conference & Exposition, 2004.

[15] M. Frank, "Assessing the interest for systems engineering positions and the Capacity for Engineering Systems Thinking (CEST)," *The INCOSE Journal of Systems Engineering*, vol. 13, no. 2, 2010.

[16] J. E. Kasser and T. Mackley, "Applying systems thinking and aligning it to systems engineering," presented at the 18th INCOSE International Symposium, Utrecht, Holland, 2008.

[17] D. McArthur, "Earth Moon Earth techniques," presented at Wireless Institute of Australia Central Region Technical Symposium, Adelaide, 2004.

[18] R. Moncur, "Digital enhancement of VHF Signals," presented at Wireless Institute of Australia Central Region Technical Symposium, Adelaide, 2004.

[19] J. E. Kasser, "Introducing Satellite Communications," *Amateur Radio (UK),*, no. May, June 1986, 1986.

[20] J. E. Kasser, "The Sky's the Limit (Amateur Communication Networks via Satellite)," *BYTE*, Nov 1978, 1978.

[21] J. E. Kasser and J. A. King, "The AMSAT Phase Three Spacecraft," presented at the International Telemetry Conference, San Diego, 1981.

[22] J. E. Kasser and V. Krondatko, "CQ Earth, this is MIR Calling," *The AMSAT Journal*, vol. 13, no. 2, 1990.

[23] A. N. Zaitsev, "The Educational Program of Youth Center "Space Communications and Informatics"," presented at First International Symposium on Space Education (UNIVERSAT-2006), Moscow, 2006.

[24] V. Mayorova, "Baumanets" student micro-satellite," presented at First International Symposium on Space Education (UNIVERSAT-2006), Moscow, 2006.

[25] J. E. Kasser, "Thirty Years of Amateur Radio in Space," presented at 11th Annual Space Development Conference, Washington DC, 1992.

[26] S. A. Sheard, "Twelve Systems Engineering Roles," presented at The 6th Annual International Symposium of the NCOSE, Boston, MA., 1996.

[27] J. E. Kasser, "Introducing the Role of Process Architecting," presented at The 15th International Symposium of the International Council on Systems Engineering (INCOSE), Rochester, New York, 2005.

[28] ARRL, *The ARRL Handbook for Radio Amateurs*: The American Radio Relay League (ARRL), 2004.

[29] H. Eisner, *Computer Aided Systems Engineering*: Prentice Hall, 1988.

[30] J. E. Kasser, "A Proposed Framework for a Systems Engineering Discipline," presented at The Conference on Systems Engineering Research, Hoboken, NJ, 2007.

[31] J. E. Kasser, "Amateur Satellite Telemetry, Past Present and Future," presented at National Telesystems Conference, Reston, VA., 1992.