Experiences in engineering design training at Samara University

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Abstract. This paper aims to share experience gained by Samara National Research University in training students in engineering degree programme "Manned and Unmanned Spacecraft and Space Systems". Core items of engineering degree curricula are projects because they basically form practical experience of future design engineers. Main items of the course project "Calculation of main parameters and generation of land remote sensing satellites conceptual design based on regard to required efficiency indices" are discussed. These include acquisition and processing of statistical data on space systems and satellites; determination of satellite orbit parameters; determination of mass-dimensional characteristics of spacecraft on-board systems and construction; formation of on-board systems; spacecraft construction models and assembly model; choice of launcher and spacehead model development. The activity is supported by appropriate training materials and software.

1 Introduction

Engineering design education is based on knowledge accumulated by students in the process of learning science, mathematics and engineering disciplines. In the context of educational programmes in space technology, those engineering disciplines include disciplines pertaining to spacecraft systems, construction and project concept.

Students also study: statement of problems of spacecraft design; choice of basic design parameters; criteria of design solutions; monocriteria and multicriteria optimization; design and construction automation.

Experience in design and engineering also evolve from academic and job training, graduation thesis preparation and course projects activities as a whole. Critical role of the latter activity is emphasized by accreditation requirements of Association for Engineering Education of Russia (AEER) and European Network for Accreditation of Engineering Education (ENAEE) [1, 2].

Curriculum of the engineering degree programme "Manned and Unmanned Spacecraft and Space Systems" implemented in Samara University includes 5 course papers and 5 course projects.

In this paper, experience in realizing a course project in the discipline "Construction and design of spacecraft, boosters and spacestations" is presented. The subject of the project is "Calculation of main parameters and generation of land remote sensing satellites conceptual design based on regard to required efficiency indices".

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2 Project statement

The initial data for the design is as follows:

- wavelength range of observation;
- number of wavelength ranges;
- ground resolution;
- swath width;
- surveillance frequency;
- satellites system productivity;
- operational efficiency;
- operating lifetime;
- upper limit of the satellite orbit altitude;
- form of the satellite body section;
- number of solar cell battery panels.

Students are also provided with their work schedule (see table 1). Recommended software, along with industry-standard application, includes the software "EFKAN", which was developed by researches of Samara State Aerospace University (SSAU) and SRC "Progress".

Table 1. The work schedule

No.	Items content	Recommended software	Volume, %	Deadline, weeks
1	Acquisition and processing of statistical data on space systems and satellites	Internet, Microsoft Office, Matlab	10	3
2	Determination of sun synchronous orbit parameters	EFKAN	15	4
3	Determination of electro-optical telescopic system (EOTS) parameters	Mathcad, Excel	30	5
4	Choice of data acquisition and digitizing system, storage device and radio data link	Internet, Microsoft Office	35	6
5	Choice of on-board control system and motion control system	Internet, Microsoft Office	40	7
6	Calculation of gyrodyne complex parameters	Mathcad	45	8
7	Calculation of complex propulsion system parameters	Mathcad	50	9
8	Calculation of temperature control system parameters	Mathcad	55	10

Table 1. (Continue)

No.	Items content	Recommended software	Volume, %	Deadline, weeks
9	Calculation of electric power supply system parameters	Mathcad	60	11
10	Formation of on-board systems, spacecraft construction models and assembly model	SolidWorks	75	12
11	Formation of preliminary weight report	Mathcad, Excel	80	14
12	Choice of launcher and spacehead model development	SolidWorks	95	16
13	Processing of explanatory note and project presentation	Microsoft Word	100	17

3 The project contents

3.1 Acquisition and processing of statistical data on space systems and satellites

This item is necessary, first, for taking into account recent advantages in spacecraft design and, second, for clarification of regression relationships that are to be applied in methodical ware and software in order to provide use of adequate mathematical models (accuracy of the spacecraft mass-dimensional characteristic calculation depends upon accuracy of models). Statistical data must be collected on satellites' characteristics and on their structures.

The data available to a design engineer, is typically heterogeneous. An attempt to develop a model based on the whole data population may result in a rather low quality of the model. Therefore, the data must be previously divided into more or less homogeneous groups. The problem may be solved by using cluster analysis [3].

3.2 Determination of satellite orbit parameters

First, orbit type is chosen. For most current technology land remote sensing satellites (LRSS), sun synchronous orbits are used. Minimum orbit altitude $H_{\min}$ may be expressed as follows:

$$H_{\min} = \frac{R_E}{\sin(\gamma_{\max})} \cdot \sin\left(\frac{L}{2R_E} + \gamma_{\max}\right) - R_E,$$

where R_E is the Earth radius, L is given swath width and $\gamma_{\max}$ is maximum deviation angle of the EOTS line-of-sight from the nadir.

Altitude and inclination of sun synchronous orbit are related as follows:

$$\cos(i) = \frac{\mu p^2 (2\pi - T_C \omega_E)}{2\pi \varepsilon N},$$

where i is orbit inclination, $\mu = 398600$ km^3/s^2 is the Earth gravitational parameter, p is orbit focal parameter, $T_C = 86400$ s is mean solar day duration, $\omega_E = 0.729211 \cdot 10^{-4}$ s^{-1} is the

Earth angular velocity, $\varepsilon = 0.003352$ is ellipticity of Earth, N is number of the satellite daily orbit passes.

If surveillance system includes several satellites, it is possible to use single orbits, but ground traces must be shifted relative to each other [4, 5].

Then, students have to estimate surveillance frequency for several survey objects and operational efficiency. Frequency of the same object surveillance depends essentially upon orbit parameters and the object latitude, while operational efficiency (operativeness of video data delivery) depends upon orbit parameters and placement of ground information receiving point. Estimation of surveillance frequency and operational efficiency can be performed with the help of the software "EFKAN". The software uses simulation of the satellite orbital movement and its target turns; as a result, statistical expectations, mean-square deviations, distribution functions and density functions of surveillance frequency and operational efficiency are calculated.

Figure 1 shows the satellite trace and zones of visibility as an example. Boundaries of the satellite zones of visibility are calculated at given time intervals [5].

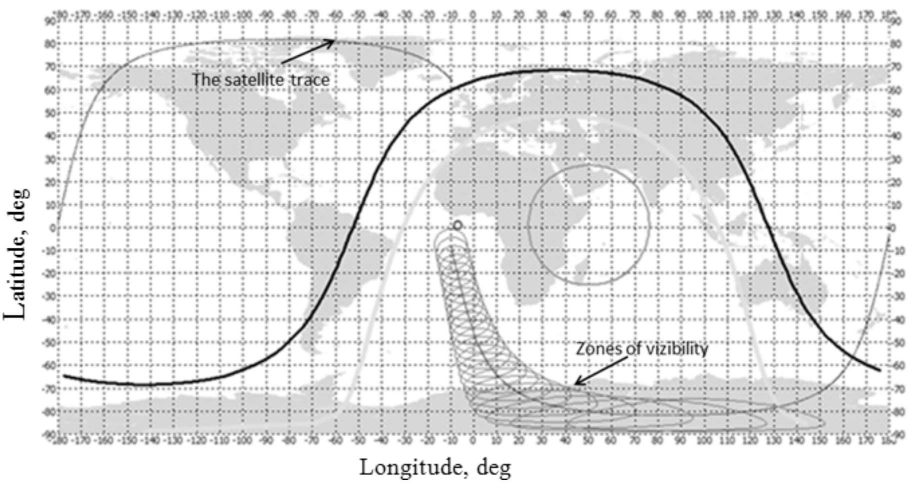

Figure 1. The satellite trace and its zones of visibility

When periodicity and operational efficiency are determined, orbit parameters, number of satellites, number of ground information receiving points are clarified, and necessity of data-relay satellite for providing operational efficiency is analysed.

3.3 Determination of mass-dimensional characteristics of spacecraft on-board systems and construction

If there is no equipment with necessary characteristics, the problem of developing new systems arises. Statistical data on various on-board systems of existing spacecraft or, alternatively, appropriate mathematical models based on physical principles of the systems operation are used. Models for estimation of target systems characteristics must include models of electro-optical telescopic system, data acquisition and digitizing system, storage device, radio data link. Models for estimation of support systems characteristics must include models of on-board control systems (gyrodyne complex, system of gyrodynes desaturation, stellar coordinate measurement unit, etc.); temperature control system (including passive and active components); electric power supply system; complex propulsion system; construction of spacecraft modules and hinged elements; antenna feeder systems; on-board cable system and on-board electronics [6–11].

Such models have been developed by researches of SSAU and SRC "Progress". They allow determining not only on-board systems and spacecraft masses, but also their dimensions and inertia moments. Those models are introduced in the education process and are accessible to all students.

One example is the model for determining parameters of charge-coupled device (CDD) array. First, it is necessary to choose an optical circuit and to estimate the equipment mass, dimension and power consumption. Choice of an optical circuit is a multicriterion problem and it has no clear solution [5, 11]. Ritchey–Chrétien optical circuit, for the most part, is considered. Cut-off frequency transmitted by a lens ν_c may be revealed,

$$\nu_c = \frac{D}{\lambda f},$$

where D is the lens diameter, λ is the wave length and f is the optical system focal length. Considering that limit resolution (difraction resolution) in focal plane is one-half of cut-off frequency, it equals

$$\Delta L_f^{\text{dif}} = \frac{\lambda f}{2D}.$$

Then, provided that electro-optical telescopic system axis is directed to nadir, ground resolution may be obtained as follows:

$$\Delta L_G = \frac{\lambda H}{2\nu_0 D},$$

where ν_0 is the ratio of operational frequency to cut-off frequency. Thus, minimal diameter of lens required to obtain ground resolution is

$$D_{\min} = \frac{\lambda H}{2\nu_0 \Delta L_M}.$$

Liner dimension of elementary photodetector δ with account for some factors such as Nyquist frequency, characteristics of CCD arrays now in use, internal equipment noise, etc., may be determined as

$$\delta = \frac{\lambda}{(0.81 \pm 0.008)} \cdot \left(\frac{f}{D}\right),$$

where f/D is lens aperture. Then, required focal length may be determined as

$$f = \frac{\delta H}{\Delta L_M}.$$

The CCD array length depends upon required field-of-view of the EOTS.

3.4 Formation of on-board systems, spacecraft construction models and assembly model

First, the satellite structure is formed based on determined mass-dimensional characteristics of spacecraft on-board systems and construction. Then, 3D models of spacecraft elements are formed in one of CAD-systems (normally, SolidWorks system is used).

Formation of the assembly model must be realized with account for set limitations and chosen criteria. As limitations, a design engineer may set areas for location of some elements (apparatus, for instance), areas for location of hinged construction elements, taking account of their potential shielding, and envelope.

Formation of the assembly model may be realized by several methods. We recommend the method of iterative "addition" of on-board systems and construction around EOTS by criterion of minimum mass and minimum inertia moments of spacecraft [4, 12]. The method is used in SRC "Progress" for "manual" iterative cycles of spacecraft design. Design works sequence using this method is shown in figure 2. An example of LRSS assembly model formed by a student is shown in figure 3.

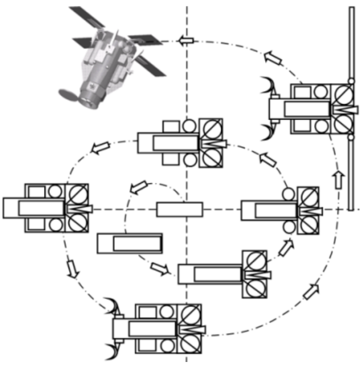

Figure 2. Sequence of spacecraft design concept formation

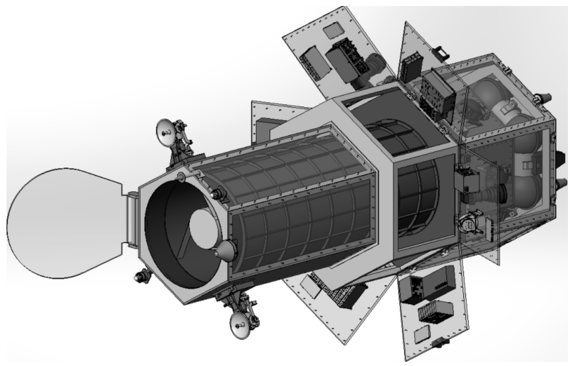

Figure 3. LRSS assembly model

When all models of on-board systems, spacecraft construction and assembly model are formed, the spacecraft weight report is developed. At this stage, balancing and inertia characteristics are determined. It is sensible to use here CAD systems, as they include tools for automated determination of those characteristics based on given values of structural elements' density.

3.5 Choice of launcher and spacehead model development

First, for the choice of launcher a design engineer has to take into account its payload capacity and dimensions of payload zone. Then, statistical data on various launchers are compared with regard for vehicle launch cost, and choice is made by criterion of minimum cost.

At this stage of the project, the spacecraft designed is placed under payload fairing (PLF) and animation picture of PLF jettison and spacecraft transfer to operational mode is realized. At the end of design process, protocols with LRSS design structure and characteristics are formed.

4 Conclusion

As it is stated [1, 2], project designs are core items of engineering degree curricula. As far as the programme "Manned and Unmanned Spacecraft and Space Systems" is concerned, the core project is "Calculation of main parameters and generation of land remote sensing satellites conceptual design based on regard to required efficiency indices".

That activity is essential for students. The reason is that it prepares them for their graduation thesis and, generally, for their future profession. As an additional incentive, our Department holds a best project contest.

Effectiveness of the engineering degree programme "Manned and Unmanned Spacecraft and Space Systems" is confirmed since 2008 by certificates of AEER and ENAEE.

References

[1] Criteria and procedure for professional accreditation of engineering programmes (AEER), URL `http://www.aeer.ru/`

[2] EUR-ACE® Framework Standards and Guidelines, ENAEE, URL `https://www.enaee.eu/eur-ace-system/standards-and-guidelines/#standards-and-guidelines-for-accreditation-of-engineering-programmes`

[3] A. Kucherov, V. Kurenkov, *Use of cluster analysis for development of star tracker mass statistical model*, Procedia Eng., **185**, 227 (2017)

[4] V. Kurenkov, *Basic principles of electrooptical survey satellites design* (Samara University Publishing House, Samara, 2020)

[5] A. Kirilin, R. Akhmetov, V. Kurenkov et al., *Generation of land remote sensing satellites conceptual design based on regard to required efficiency indices*, Procedia Eng., **104**, 65 (2015)

[6] M. Moldabekov, D. Akhmedov, S. Yelubaev et al., *Development of star tracker for satellite*, in Proceedings of the 3rd International Conference Scientific and Technological Experiments on Automatic Space Vehicles and Small Satellites, 9–11 September 2014, Samara, Russia, 107 (2014)

[7] S. Garbuk, V. Gershenzon, *Space systems for land remote sensing* (A and B Publishing House, Moscow, 1997)

[8] R. Schowengerdt, *Remote sensing: models and methods for image processing* (Elsevier, Amsterdam; Academic Press, Burlington, 2007)

[9] A. Chandra, S. Gosh, *Remote sensing and geographic information systems* (Alpha Science, 2006)

[10] V. Lebedev, *Space problems of Earth remote sensing*, Herald of the Russian Academy of Sciences, **78**, 136 (2008)

[11] Ye. Somov, S. Butyrin, A. Butko, *Satellite gyromoment guidance at area land survey based on sequence of the scanning observation courses*, in Proceedings of the 18th Saint Petersburg International Conference on Integrated Navigation Systems, 30 May—1 June 2011, Saint Petersburg, Russia, 323 (2011)

[12] V. Kurenkov, A. Kucherov, *Methodology and Software for Estimating Target Efficiency of Land Remote Sensing Satellites at the Stage of Design*, J. Phys.: Conf. Ser., **1368**, 042037 (2019)