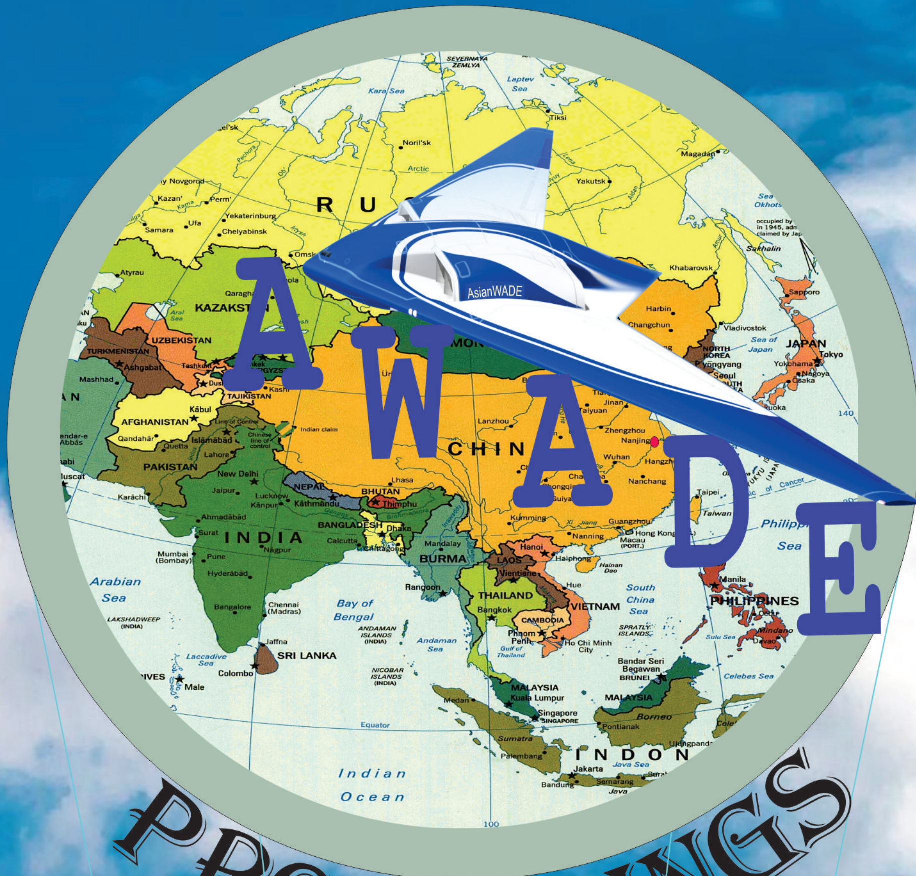

PROCEEDINGS

of the 1st seminar of Asian Workshop on Aircraft Design Education

October 08-11
2016

NUAA

Nanjing, China

Proceedings

of the 1st AWADE Seminar

Asian
Workshop
on Aircraft
Design
Education

Nanjing, China, October 08-11 2016

Nanjing University of Aeronautics and Astronautics

Proceedings of the 1st AWADE Seminar

A new form of cooperation between those involved in aviation design opens in 2016 – Asian Workshop on Aircraft Design Education (AWADE). This form of activity in the field of aircraft design in education involves seminars and student Olympiads, executing a joint project, the preparation of educational and methodical literature, etc. All these diverse activities have one goal – to improve the process of training students in the field of aircraft design. The workshop takes place at the Nanjing University of Aeronautics and Astronautics and is the first such event. The Proceedings of the 1st AWADE Seminar includes reports of participants from 7 countries. The seminar runs from October 8-11, 2016, at NUAA in Nanjing.

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1 INTRODUCTION

The aerospace industry plays a large economic and strategic role in every highly developed country. The modern state of the world shows that the biggest rates of growth in this industry are Asian countries, namely China and India. Russia's aviation industry has begun its revival. Others countries also aspire to increase this important aspect of their economy. Consolidation of efforts by countries working together should help to speed up this process in its various directions.

To ensure that this sector can give effective results, we need to have at least three successful components: education, science and production. All of these components are interconnected, but education must always be the primary constituent as it provides the participants for all three components, including itself.

The popular phrase "Personnel decide everything" is an absolute truth. If we want to progress in the aerospace industry, it is necessary to begin the initial steps of that progress from the point of view of education. All of us know that this type of education is very specific, it requires maximum investment and it, in turn, should be supported, at a high level, from the side of science, and also from production. An important role in the training of aviation professionals is the discipline of aircraft design.

So, how do we make this discipline more effective for studying? How do we provide a better understanding it of to our students? How do we direct its ability in order to implement the students' fresh ideas and dreams? These questions have always existed and always remain relevant.

In November 2015, the participants of a seminar by the Institute of Aircraft Design Technology of Nanjing University of Aeronautics and Astronautics, decided to organize a regular Workshop on Aircraft Design Education on the Asian continent. Its function was to be similar to that of the European Workshop on Aircraft Design Education (EWADE), and it was to be called the Asian Workshop on Aircraft Design Education (AWADE). This workshop should be held with contributions from experts in the field of Aircraft Design from all countries and EWADE as well.

AWADE is a joint event of aerospace industries, universities, academia, organizations and associations. It provides a unique opportunity to communicate, share, and debate innovative concepts and technical solutions in the domain of aircraft design. AWADE seminars have to promote the establishment of knowledge and technical networks with the aim of increasing Asian competitiveness in the field of aerospace. An important part of AWADE must be its methodological component.

Modern life is very informative and at first sight it is very attractive, but it creates additional difficulties for the educational process. Often students and young teachers don't ponder questions for very long before referring to the Internet for answers. This makes us all hostages to this information system. Often a graduate with a degree in aeronautics can not only not draw a beautiful airplane, but he or she cannot draw as much as an elementary aircraft, entrusting the design task instead to a computer. How do we ensure the rational combination of information capabilities as well as the development of independent creativity? Methods of teaching design should focus precisely on a reasonable combination of your own thought processes coupled with the information capabilities available to us today.

The works presented at the workshop should be linked to the following topic areas:

- Content of the subjects, their volume and distribution by semester for various forms of training
- The solution of topical issues in the field of aerospace engineering with the participation of undergraduate and graduate students
- The content and role of practice
- Education collaborative engineering in aircraft design: integrated physical teams and virtual manufacturing.
- Future education and training needs (life-long) for aerospace-engineers and researchers in Asia
- Effective interaction of education, science and production
- The content of projects and participation of students in real design
- Virtual testing in aerospace education: future role of large scale testing.

Examples of students' participation in solving scientific problems and practical developments

- Career Guidance of school kids for aerospace engineering

2 EWADE

The Asian aerospace industry and, accordingly, aerospace education, are young, and it is necessary to use accumulated experience to introduce new progress. To find that accumulated experience, we need look to Europe. Great importance is attached to the correct organization of the educational processes in the field of Aeronautics and Astronautics on the old continent. In particular, this applies to such complex and demanding areas as aircraft design. The rich experience of the European seminar, EWADE, can help us with this process.

By 1990, the big questions in terms of education problems facing this field of study had accumulated into quite a large folder. To decide these and other questions in Europe, the first European Workshop on Aircraft Design Education (EWADE) was organized. This European Workshop was formed as a forum for academic staff working in aircraft design education in European universities.

The first European Workshop was held in Madrid in 1994. There were approximately 25 participants from 10 countries. Other workshops followed, often with an increasing number of participants. All of the workshops were arranged with financial support and contributions from the industry. Since 1994, EWADE has become known as an affectionate community of people with similar interests. Today, everyone is welcome to participate and to contribute with a presentation or poster.

For the first time, EWADE was announced as an activity under Council of European Aerospace Societies (CEAS) and was listed on the CEAS Calendar under the guidance of the Technical Committee (TC) Vehicle Design. CEAS is an organization bringing European national aerospace societies together for increased international strength.

Today, CEAS comprises 16 member organizations and brings together roughly 35,000 professionals in aerospace. Since 2007, CEAS has hosted biennial aerospace conferences in Europe. We can see in this list of member organizations, the oldest and most authoritative research organizations in the field of aerospace: for example, from the UK (RAES – 1866), Germany (DGLR – 1912), RU (ThAGI – 1918), AIDAA (IT–1920) and others.

CEAS states that its objective is to... "to promote international cooperation through Memoranda of Understanding" with "The International Council for the Aeronautical Sciences" (ICAS), "The American Institute for Aeronautics and Astronautics" (AIAA) and others. The Chinese Society of Aeronautics (CSA) also cooperates with CEAS.

After the Madrid Workshop in 1994, it was agreed that workshops would be organized every two years, hosted by those participants who can find sufficient financial support from their universities and from their local or national industry.

Objectives are formulated as follows:

– To allow European lecturers concerned with Aircraft Design to continue their active collaboration.
– To discuss Aircraft Design problems as regards research and education.
– To enhance close cooperation with the aerospace industry for the two aspects mentioned above.

Figure 1: Map of Participants of EWADE

The brief history of EWADE:

- 1st Workshop: 1994 Madrid(Spain)
- 2nd Workshop: 1996 Berlin(Germany)
- 3th Workshop: 1998 Bristol(England)
- 4th Workshop: 2000 Turin(Italy)
- 5th Workshop: 2002 Linköping(Sweden)
- 6th Workshop: 2004 Brno(CzechRepublic)
- 7th Workshop: 2005 Toulouse(France)
- 8th Workshop: 2007 Samara(Russia)
- 9th Workshop: 2009 Sevilla(Spain)
- 10th Workshop: 2011 Naples (Italy)
- 11th Workshop: 2013 Linköping (Sweden)
- 12th Workshop: 2015 Delft (Netherlands)
-

The next EWADE 2017 will be organized together with READ (Research and Education in Aircraft Design) and SCAD (Symposium on Collaboration in Aircraft Design) under CEAS 2017 in Bucharest. The conference will start on 17th September 2017.

3 NUAA: NANJING UNIVERSITY OF AERONAUTICS AND ASTRONAUTICS

Nanjing University of Aeronautics and Astronautics (**NUAA**) is a public university located in Nanjing, Jiangsu province, China. It was established in October 1952. In Chinese, the university name is sometimes shortened to **Nanhang** (南航). The university is operated by Ministry of Industry and Information Technology and is one of China's leading universities in research and education. As per QS World University Rankings, it is one of the top 300 universities of the world in Mechanical Engineering and one of the top 200 universities of Asia. It is regarded as one of the top engineering universities in China and also has a great influence on China's aerospace industry

The school was founded in October 1952, as the **Nanjing College of Aviation Industry**. In 1956 it was renamed as **Nanjing Aeronautical Institute**, and, in 1993 as the current name, **Nanjing University of Aeronautics and Astronautics**. Since 1952, NUAA has evoloved from a teaching-oriented university to a research-oriented university and currently administered by the Commission of National Defense Science, Technology and Industry.

NUAA mainly offers courses in science and engineering and strives for the coordinated development in applied science, management, humanities and social sciences with the combined features of aeronautics, civil aviation and astronautics. It is among the nation's first institutions of higher learning authorized to grant degrees of Doctor, Master and Bachelor. In 1996 it succeeded in becoming one of the national top 100 key universities for the 21st century (China's Project 211). It is subordinated to the Ministry of Industry and Information Technology of the People's Republic of China.

NUAA has attached great importance to scientific research and shown great advantages in the research of basic sciences, the application of high-tech and the development of national defense technology. During the 9th Five-Year-Project, NUAA took on 600 science and technology development projects including the "863 Program" and some national defense projects. Many have been successfully applied. Since 1978, NUAA has received 917 provincial awards and 49 national awards for scientific research. It has remained one of the top 10 universities in China since 1991 in terms of the total number of achievements and awards in science and technology research and development. At the same time, NUAA has always paid great attention to the quality of education and the development of its students. Since 1989, NUAA has won a total of 63 Teaching awards at provincial levels, 18 of which are of national distinction. Students from NUAA have perfomed well in the National competition of Mechanics and Mathematical Modeling for undergraduates. So far NUAA has produced more than 55,000 talents in different specialties. As one of the most famous universities in Nanjing city, it has attracted more and more international students for its excellent study environment and conditions in recent years, and it also takes great advantages in some key courses, including Flight Vehicle Design and Engineering, Computer Software Design and Internal Economics & Trade and so on. Among all the specialties in the College, Flight Vehicle Design is a national key specialty.

NUAA has 18 colleges:

- **College of Aerospace Engineering**
- College of Energy and Power Engineering
- College of Automation Engineering
- College of Information Science and Technology

- College of Mechanical and Electrical Engineering
- College of Material Science and Technology
- College of Civil Aviation
- College of Natural Sciences
- College of Economics and Management
- College of Humanities and Social Sciences
- College of Advanced Vocational Education
- College of Astronautics
- College of Arts
- College of Foreign Languages
- College of Computer Science and Technology
- Jincheng College
- Graduate School
- Academy of Frontier Science
- College of International Education

NUAA's museum of aviation

NUAA offers a wide range of programs including 46 undergraduate programs, 127 master programs and 52 doctoral programs. 2 first grade and 9 second grade disciplines are awarded national key disciplines. The former includes Aerospace Science & Technology and Mechanics. The latter includes Aircraft Design, Aerospace Propulsion Theory & Engineering, Manufacturing Engineering of Aerospace Vehicle, Man-Machine and Environmental Engineering, General and Fundamental Mechanics, Solid Mechanics, Fluid Mechanics, Engineering Mechanics, Mechanical Manufacture & Automation. 8 disciplines are key disciplines of the Commission of National Defense Science, Technology and Industry, such as Tele-Communication & Information Systems, Technology of Micro Air Vehicles, etc. 10 disciplines are key disciplines of Jiangsu Province, such as Mechanical Design and Theory, Navigation Guidance & Control, etc. 4 disciplines such as Aircraft Design, Mechanical Manufacture & Automation, Engineering Mechanics, Manufacturing Engineering of Aerospace Vehicle are especially set up for "Changjiang Scholar Award" professors. Besides, NUAA has set up 12 postdoctoral programs, such as Aerospace Science & Technology, etc.

The university started enrolling international students largely since 2005 after the establishment of the College of International Education. Currently there are over 470 undergraduate international students from 40 countries.

The university has been enrolling post-graduate international students for several years as well. Dozens of Master and Ph.D-level students have since graduated with various majors and specialties. It also provides scholarships to outstanding international students at both undergraduate and post-graduate levels under various government scholarship schemes including the China Government Scholarship and Distinguished International Students Scholarship schemes.

Apart from full-time students, NUAA has been hosting exchange students from universities in Australia, Canada, France and Germany. Every year, under the university's exchange and summer programs with international universities, dozens of international students come to NUAA to study at both undergraduate and post-graduate levels.

As one of the best colleges in NUAA, the College of Aerospace Engineering is a teaching and research college with multi-disciplines, excellent academic quality and good engineering capabilities. After the change in 2000, it has enlarged its scale. At present it has four departments: Department of Aircraft; Department of Aerodynamics; Department of Structural Engineering and Mechanics; Department of Man-Machine and Environment Engineering.

With its powerful research ability, it also has nine institutes and three research centers. The nine institutes are: Institute of Helicopter Technology; Institute of Aeroplane and Spacecraft Technology; Institute of Aircraft Environment Control and Life Protection Engineering; Institute of Refrigeration and Air-conditioning Technology; Institute of Vibration Engineering; Institute of Structural and Intensity Control; Institute of Smart Materials and Structural Study; Institute of Aerodynamics; Institute of Aircraft Maintenance Technology.

The three research centers include Mini-Flight Vehicle Center; CAD Center and Supersonic Electrical Machinery Research Center. There is also an Aerospace Technology Exhibition Hall.

Various laboratories it owns also play an important role in its research activities. And some especially important labs are: Helicopter Rotor Dynamics Lab (national key laboratory), Smart Material and Structure Lab (ministerial key laboratory), Vibration Engineering Lab (ministerial open laboratory), Aerodynamics Lab (ministerial open laboratory), Mechanics Teaching and Experiment Center at provincial level.

Among all the specialties in the College, Flight Vehicle Design is a national key specialty, and Engineering Mechanics is a Provincial key specialty. There are also several key academic societies at different levels: Chinese Society for Vibration Engineering; Chinese Aeronautic Society for Helicopter Specialty and so on.

Since 1981, it has established a wide and close corporation relationship with some famous foreign universities in America, Russia, Britain, and France and so on. Some important international meetings were also organized in the college, which has increased the strength of it. And in 2005 it began to receive international students.

The university has undertaken a large amount of development work. It has strong links with the Chinese aviation industry. Leading experts from all countries are invited to teach many different disciplines, including “Aircraft Design”. University graduates who have studied aircraft design here are highly rated and in high demand.

4 CONCLUSIONS

As we can see, the choice of NUAA for AWADE is well founded. Even the presence of art college is rightly so, since, as will be discussed in one article of this collection – Design is not only a science, but also an art.

Starting any business is not easy. But the organizing committee of AWADE believes that the 1st Asian Workshop, held in NUAA, will give the necessary impetus for its continuation in future activities in a variety of formats, and not only in Asian universities. The English Word "Workshop" has many meanings, and, in this regard, AWADE will include not only seminars and conferences, but also a student Olympics, international joint projects on various problems in the field of aircraft design and much more.

良好的开始是成功的一半

A good beginning is half the battle

千里之行，始于足下

The journey begins with a single step

Organizing Committee of AWADE-2016

Asian Workshop on Aircraft Design Education
AWADE 2016
Nanjing University of Aeronautics and Astronautics (NUAA), 08-11 October 2016
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Teaching Aircraft Conceptual Design at the Undergraduate and Graduate Levels

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Key words: Aircraft design, teaching, aircraft sizing, aircraft performance

Abstract:*Overview of syllabus for teaching a class in aircraft conceptual design at the fourth year undergraduate or graduate level*

1 INTRODUCTION

This paper provides abrief overview of a syllabus for teaching aircraft conceptual design based on the author's experience working in the advanced design department of a major US aircraft manufacturer, and teaching in several US and foreign universities.

The syllabus in any course is strongly affected by the textbook selected by the instructor, and several English-language books are available [1,2,3,4]. Raymer [1]is used in many design courses in the US. The course concentrates on those aspects of conceptual design that are the responsibility ofdesigners and analysts in the conceptual/preliminary design department. The course is also useful to engineers in other technical disciplines who contribute to conceptual or preliminary design, and help them understand their contributions and the necessary trades that must be made between different technologies.

One of the goals of the course is to teach students the procedures for aircraft conceptual design. But progress is only achieved by adopting new ideas and concepts, and another goal should be to encourage students to innovate. Unfortunately a one-semester course may not provide sufficient time to quantify the benefits of new ideas. For example, conceptual design weight estimation methods are based on analyses of weights of past and current airplanes, so it is difficult to estimate the weight reduction from a strut-braced wing from either Raymer's [1] or Nicolai's [3] weight equations(although this can be estimated from Torenbeek's or Cessna's methodsreproduced in Roskam's text [4]).It may be very difficult to estimate the empty weight of a truly novel concept.

Even so, it is worth introducing students to unique and innovative concepts at the start of the course. Examples of these are described in Raymer, Ch. 22. Many more can be found online. Discussion of what the designers were trying to achieve, and why they designed certain configurations, is a useful introduction to the design process, and helps to explain why airplanes for a given mission often look similar. Canard aircraftdeserve special attention forcomparison with conventional configurations.

Class notes, presentations, sample spreadsheets,descriptive bibliography, and related notes pertaining to Raymer [1] and Schaufele [2] may be found at the website shown at the top of this page.

2 DESIGN REQUIREMENTS

Establishing military design requirements may take ten years or more to develop, with requirements changing over time as a result of evolving threats, available technologies, or shifting politics. For commercial airliners, requirements are usually defined by a team comprising the manufacturer and one or more airlines who will be initial operators, and this process may take only a couple of yearsThe requirements team must agree on the technology readiness level (TRL) of the technologies that will be employed in the design. For commercial aircraft, this should be TRL 7 or greater, but for military applications the value will typically be lower.For this course the requirements document is usually provided by the instructor, or the students compete in an AIAA student design competition for which requirements may be military, commercial, or general aviation.Students should also be introduced to the relevant Federal Aviation Regulations (FARs), especially Parts 1, 23, 25, 36, 91 and 121.

An important part of the requirements document is the mission profile, which for business jets should be defined by the National Business Aircraft Association (NBAA) rules, or for larger passenger-carrying aircraft by FAR 121.639 (US domestic operations), or FAR 121.645 (international operations).

3 THE ATMOSPHERE AND AIRSPEEDS

In many textbooks (including Raymer and Nicolai & Carichner), the characteristics of the standard atmosphere and the definitions of various airspeeds are relegated to appendices. Schaufele introduces these in the first chapters, and this is the preferred approach. It is particularly important for the student to understand the difference between true airspeed (TAS), equivalent airspeed (EAS), and indicated airspeed (IAS).

4 INITIAL ESTIMATE OF TAKEOFF GROSS WEIGHT

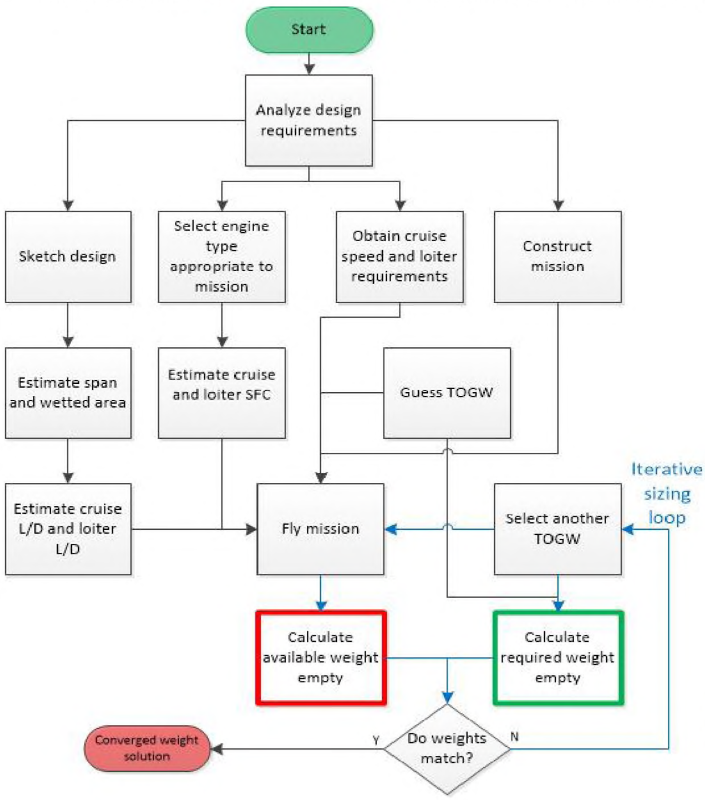


Figure 1: Flowchart for Initial Sizing

In industry, preferably two or more design concepts aredeveloped through the conceptual (and possibly preliminary) design process, with downselect by an integrated product team (IPT) which includes various technical disciplines. Raymer's bookdescribes one such development. An initial 'sketch' is drawn (but more realistically a three-view drawing) for which takeoff gross weight (TOGW), thrust/weight (T/W) and wing loading (W/S) have not yet been calculated. One of thefirst analytical tasks is to estimate the TOGW required to perform the design mission (Fig. 1).

If the relationship between empty weight required (using Nicolai's terminology) and TOGW is non-linear, based on statistical relationshipsof similar aircraft (e.g., single aisle, twin-engine airliners), or component weight buildup, then "empty weight matching" is the preferred method, i.e., matching empty weight requiredwith the empty weight available, based on analytically flying the aircraft on the design mission, and subtracting fuel, crew, and payload weight from the assumed value of TOGW (Fig. 2). This is an iterative process, and may be solved manually, graphically using the Solver add-in to MS Excel, or other computer software. Fig. 2shows empty weight required as a linear function, in which case iteration would not be required, but in practice it is not quite linear.

If the takeoff gross weight is expressed as:

$$W_0 = W_{crew} + W_{payload} + W_f + W_e \qquad (1)$$

where W_0 = takeoff gross weight
W_{crew} = crew weight
$W_{payload}$ = payload weight
W_f = mission fuel weight, including reserves
W_e = empty weight required

then

$$W_0 = \frac{W_{crew} + W_{payload}}{1 - (\frac{W_f}{W_0} + \frac{W_e}{W_0})} \qquad (2)$$

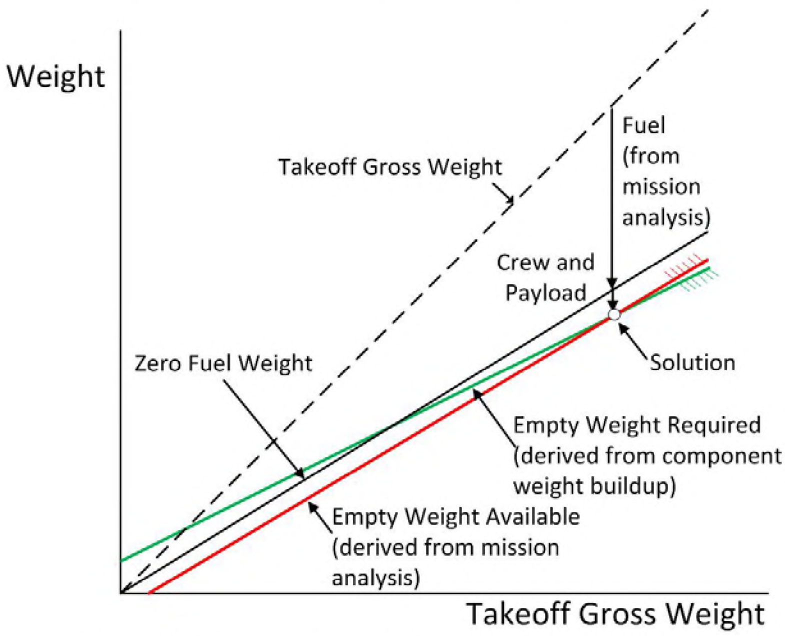


Figure 2: Illustration of Empty Weight Matching

The fuel fraction is determined using the Breguet range equation, plus estimates of fuel burned in takeoff and landing. Eq. (2)and Fig. 2 reveal an inherent difficulty with estimating takeoff gross weight. If the crew plus payload weight is small as a fraction of takeoff gross weight,then the fuel plus empty weight fraction approaches unity. This makes the denominator of the equation very small, and very sensitive to either fuel fraction or empty weight required fraction.Both of these values are rather rough estimates. In the Breguet range equation, both lift/drag ratio (L/D) and specific fuel consumption (sfc) are estimates, and the empty weight required ratio is based on the class of aircraft, and not related to the drawing. The reality is that in industry, this step may be skipped entirely,and the initial value of TOGW is simply based on that of a competitive aircraft; detailed sizing is done with an "industrial-grade" program which contains more detailed methods for estimating performance variables and weights.

Nevertheless, it is worth introducing the process of empty weight matching early in the design process. It is the process used in industrial-grade sizing programs, using more accurate methods for calculating L/D, sfc, mission definition, and empty weight required. These will be introduced to the students later on in the course.

If MS Excel (with Solver installed) or MATLAB code has been written to size the aircraft, then it is easy to do an initial sensitivity analysis (Table 1) to give students a good idea of the sensitivity of assumptions to TOGW.

Configuration	$(L/D)_{max}$	Cruise sfc	Empty weight reduction factor	Empty weight	TOGW
Baseline	18.0	0.50	1	???	???
L/D improvement	19.8	0.50	1.0	???	???
SFC improvement	18.0	0.45	1.0	???	???
Empty weight reduction	18.0	0.50	0.9	???	???
All technologies applied	19.8	0.45	0.0	???	???

Table 1: Example of Initial Sensitivity Analysis

5 THRUST/WEIGHT AND WING LOADING

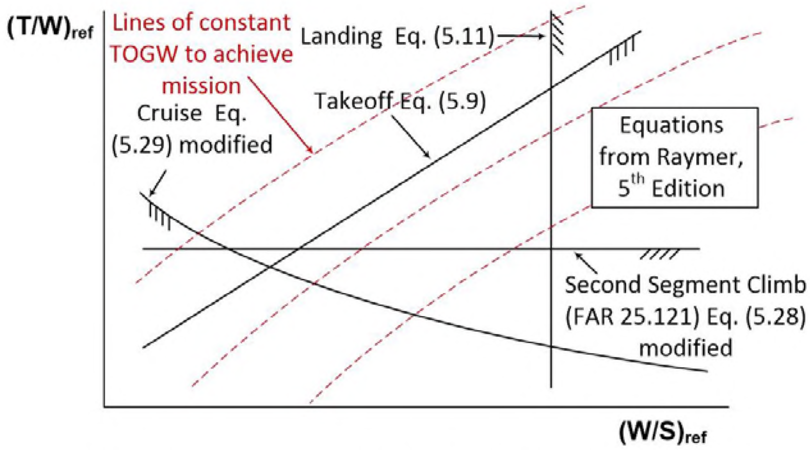


Figure 3: T/W vs. W/S Plot for Commercial Aircraft

In both Raymer's, and Nicolai & Carichner's, textbooks the concept of the thrust/weight $(T/W)_{ref}$ and wing loading $(W/S)_{ref}$ constraint plot is not introduced to students until quite late in the book. This leaves students wondering what the relationships are between $(T/W)_{ref}$ and $(W/S)_{ref}$, and how they constrain the design. Roskam [5, Vol I] introduces this constraint plot early in the design process, and this is the preferred approach. Using Raymer, it is possible to generate a slightlysimplified plot using equations in Chapter 5, with some minor modifications, as shown in Fig. 3.

Note that the values of T/W and W/S are reference values, usually defined by:

T_{ref} = Installed thrust at sea level static, standard day conditions, all engines operating
W_{ref}=Maximum takeoff gross weight (usually ramp weight)
S_{ref} = Reference wing area (usually trapezoidal, but Boeing and Airbus use different definitions).

Often the suffix $_{ref}$ is implied, but it is important to ratio the values,calculated at the appropriate point in the mission, to the reference values. Takeoff gross weight is a useful proxy for aircraft operating cost, because the two are closely related, so minimizing takeoff gross weight is a good first-order goal. Contours of takeoff gross weight to perform a subsonic commercial airliner mission are superimposed on the figure. Those of a military aircraft are often similar (see Raymer Fig. 19.3), but those of a supersonic airliner or UAV may be very different. Generating these contours requires more information than is available to the students at this point in the design process, but the contours illustrate that for a subsonic airliner a constrained minimum gross weight configuration lies somewhere along the takeoff constraint line. Values of $(T/W)_{ref}$ and $(W/S)_{ref}$ should be selected that are far from the landing constraint line to provide for future growth in TOGW without exceeding the landing constraint.

The location of the takeoff and landing constraint lines are a function of the design takeoff and landing lift coefficients. A higher takeoff lift coefficient may result in a lower value of $(T/W)_{ref}$. Quantifying this trade (higher wing weight vs. reduced engine weight) is beyond the capabilities of the student at this time. Values of lift coefficient for takeoff and landing should be selected that are based on comparable aircraft. An industrial-grade sizing and performance program will generate plots similar to Fig. 3.

6 LAYOUT AND LOFT

Student teams of four or five students should have at least one member who is proficient in computer-aided design (CAD). However, hand-drawn drawings are preferable to crude CAD drawings. Vehicle Sketch Pad (www.openvsp.com) may be used to generate the outer mold line (OML). When the design is reasonably firm, the designer should also generate a model of the primary load-carrying structure ("bones drawing") and also show where the major components, such as cockpit, passenger cabin (or other payload bays), fuel tanks, landing gear, avionics bay, environmental control system, radar, and other systems are located. For passenger aircraft, attention must be paid to both regular exits and emergency exits defined by FAR 25.807. For military airlifters, the ability to load bulky cargo (if required in the request for proposal), such as large vehicles or weapons, must also be demonstrated.

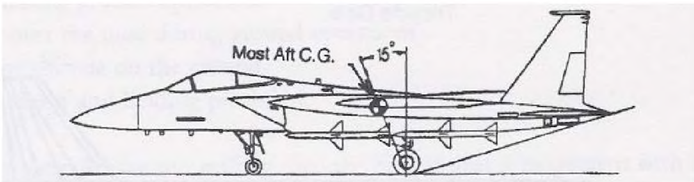
Students should examine cutaway drawings of similar aircraft, of which many can probably be found on the internet. Why are commercial airplanes and military airlifters so different structurally from fighters? What are the primary loads, both point loads (such as landing loads), and distributed (such as lift), and how are these loads carried through the structure? Students must get a good feel for these load paths, even though they may not have enough time for quantitative evaluation. Students should also understand why components, such as the auxiliary power unit (APU) are usually placed in a certain position. For military aircraft design, a qualitative discussion of stealth characteristics is required.

Wing design is a separate technical discipline, and in a design office the designer will work closely with aerodynamicists, structural engineers, stability and control engineers, and others, to optimize the wing. Airfoil section properties as a function of spanwise location are mostly the responsibility of the aerodynamics group, but overall characteristics (aspect ratio, sweep, thickness/chord, taper ratio) are joint responsibilities. Optimization may be either graphical or using multidisciplinary optimization (MDO) software. In the student environment, there is usually insufficient time for this, and students may have to select values based on competitive aircraft.

7 LANDING GEAR AND SUBSYSTEMS

Particular attention must be paid to landing gear location and retraction. An initial assumption must be made of the forward and aft center of gravity (c.g.) locations. Based on data in Torenbeek [5], for commercial designs or airlifters, a range of 15% to 35% of the mean aerodynamic chord (MAC) is reasonable, with a nominal value of 25% MAC. For fighters a nominal range of 20% to 40% can be assumed.

For conceptual design a 15^0 angle between the aft center of gravity and main landing gear trunnion (Fig. 4) is usually acceptable, although additional design analysis may show that this angle can be decreased by a few degrees for an unswept wing, and must be increased for a highly swept wing.



Source: Schaufele

Figure 4: Location of MLG Relative to Aft c.g.

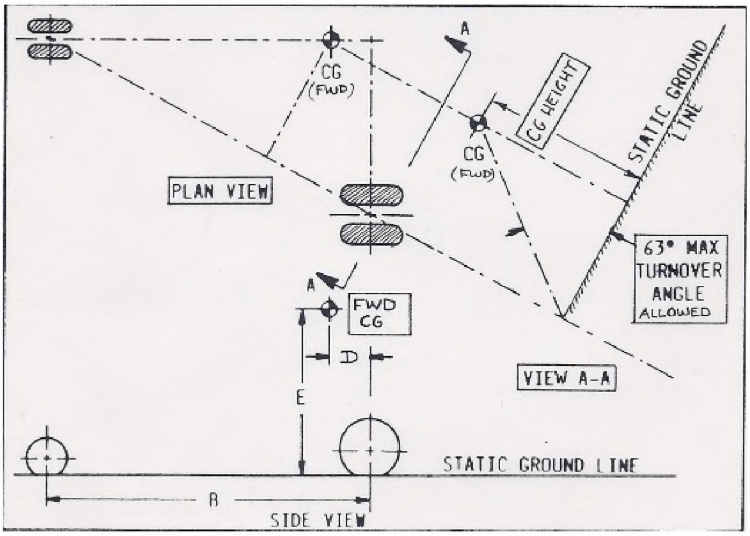


Figure 5: Calculation of Lateral Tip-over Angle

Students often have difficulty generating the scrap view, shown as VIEW A-A in Fig. 5 to illustrate compliance with the 63^0 maximum angle for lateral tipover. The scrap view is a view looking along the axis parallel to the line between the center of the nose landing gear trunnion (projected vertically on to the ground) and the center of the main landing gear trunnion, similarly projected. The value of 63^0 represents a one-half g lateral turn on a taxiway. This requirement can usually be met quite easily for an aircraft with wing-mounted main landing gear, but more difficult to meet for fuselage-mounted gear. For carrier-based aircraft, the value is usually 54^0.

7 PROPULSION SYSTEM SELECTION AND LOCATION

For students, selecting an engine with characteristics that best match the mission requirements is difficult, and at the most simple level may be based on an engine with static thrust that most closely meets that required by performance analysis, and has a bypass ratio that is similar to that of competitive aircraft.

Selecting the wrong engine location for an aircraft type has doomed some aircraft programs, and it is worth discussing the various trades involved. For commercial aircraft, they usually involve many aircraft characteristics, such as maximum lift coefficient ($C_{L_{max}}$), minimum control speed(V_{MC}), longitudinal stability, empty weight fraction, maintainability, passenger and cargo loading, and interior noise.

8 AERODYNAMICS

Generating C_L vs. α plots is described in a fairly straightforward manner in most textbooks. Raymer and Nicolai & Carichner referenceαvalues to the wing reference plane, rather than the fuselage reference plane as used in Schaufele and Torenbeek, the latter whichis standard for commercial aircraft. The difference between the two planes is selected by the designer, and is a function of the desired fuselage attitude during cruise.

Calculating zero-lift drag is also straightforward, and almost all textbooks use the same procedure, although few present the calculations in a tabular format that is suitable for spreadsheet analysis. Estimation of incompressible drag due to lift (universally, but incorrectly, referred to as 'induced' drag) is also fairly straightforward. Using the methods of Shevell [6], Schaufele provides a method for calculating the effect of the fuselage on drag due to lift.

Estimating the effect of compressibility on drag due to lift is difficult, in part because of disagreement about definitions. The Boeingdefinition of drag divergence Mach number (M_{DD}) isthe Mach number at which the drag is 20 counts (or ΔC_D = 0.0020) above the incompressible value. The Douglas definition (also used by the US Air Force and by other researchers in this area) is the Mach number at which dC_D/dM = 0.10. In general, the Douglas definition is preferred. Raymer also states that the Douglas value of M_{DD} is about 0.06 above the Boeing value. In practice, this difference can vary considerably, and sometimes the Douglas definition produces a value that is less than that of the Boeing definition. This is due to large differences in the shape of the drag rise for different airfoil sections. This can be seen in the numerous drag plots (i.e. sets of curves of C_D as a function of M for different values of C_L) in Obert [7]. A notional plot is shown in Fig. 6.The best that can be done is to admit that whatever results are generated can only be approximate.

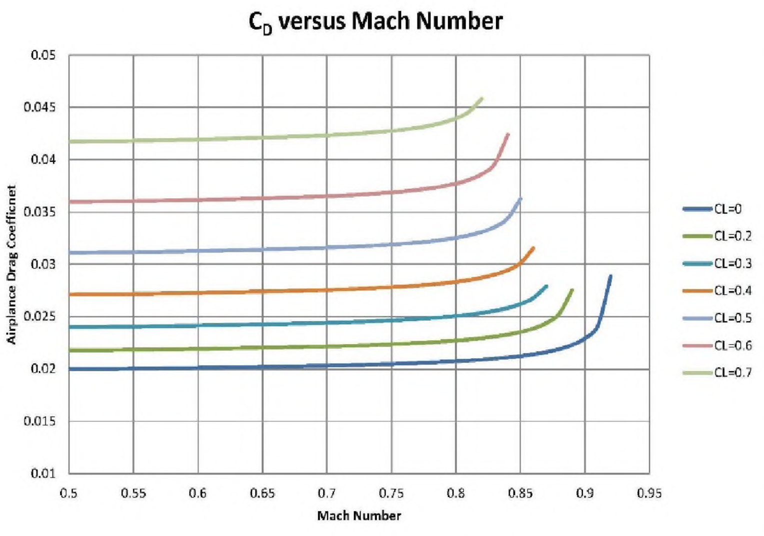


Figure 6: Spreadsheet-generated Notional Drag Plot

The drag plot does not appear in Raymeror Nicolai & Carichner, although it is probably the single most useful way to compare the aerodynamic efficiency of high-speed subsonic aircraft. Two additional plots are derived from the drag plot: a plot of L/D vs. C_L, and a plot of ML/D vs. C_L. bothfor different values of Mach number. The latter plot provides confirmation for selection of the cruise Mach number. A procedure for generating these plots is described in Schaufele. The critical issue is the method for estimatingM_{DD}. Options are to use one of the following: 1) the chart in Raymer, 2) the chart in Schaufele showing M_{DD} as a function of average t/c, C_L and wing sweep, 3) the Korn equation([8], Section 9.15), or 4) DATCOM [9]. Schaufele's chart ([2], Fig. 4.8), or the Korn equation, are the preferred methods for generating an equation for M_{DD} as a function of wing geometry to insert in a spreadsheet. The Korn equation contains a constant (κ) which allows more advanced wing technology to be assumed.

Supersonic zero-lift drag and drag due to lift can only be approximated without using methods beyond those available to students. These approximate methods are described in Raymer and Nicolai & Carichner. An explanation of the significance of area ruling provides an example of a major breakthrough in aerodynamics.

A qualitative explanation of winglets, vortex generators, and other flow modification methods should also be discussed.

9 STRUCTURES AND LOADS

Students should be able to generate the maneuver *V-n* diagram and estimate the gust *V-n* diagram (the exact diagram requires detailed computational analysis). They should also understand the relative benefits of different structural layouts and materials.Simple loads analysis is usually left to a two-semester course.

10 WEIGHT ESTIMATION

Most textbook weight equations only apply to the most common configurations, and it is difficult, for example, to do a trade study on transport aircraft engine location, because the weight equations for both wing and fuselage may not include that variable. Torenbeek's methods include wing weight reduction for engines mounted on the wing although they not consider spanwise location. Nor do they include the additional fuselage bending weight penalty from having engine mounted on the rear fuselage. Just about all weight equation systems do allow parametric evaluation of aspect ratio, sweep and t/c, but the location of the optimum configuration is strongly dependent on the equations themselves, which do not consider every design feature. So the benefit of doing such a trade study is questionable. Roskam's Airplane Design, Part V [5] probably has the most comprehensive set of weight equations, and includes those of Cessna, USAF, and Torenbeek.

11 STABILITY AND CONTROL

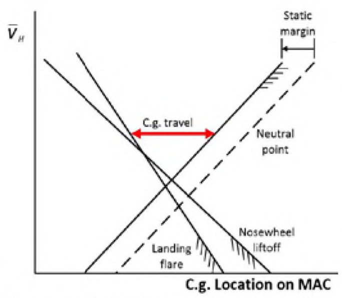
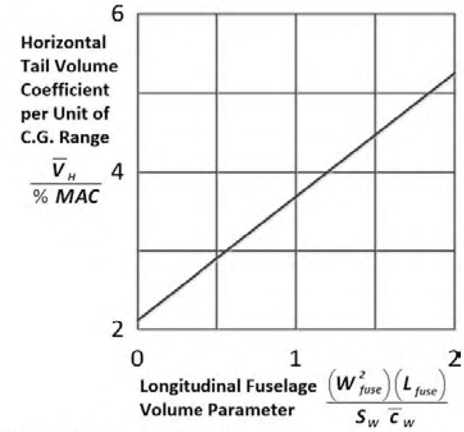


Figure 7: Notch Chart to Calculate $\overline{V}_H$

For commercial airplane designer, one of the most important stability requirements is that for the most critical c.g. location the aircraft must have a positive static margin, as required by FAR 25.175. Students must appreciate the importance of getting the c.g. travel forward of the neutral point. For a fighter the static margin may be negative, and adequate longitudinal stability achieved artificially.

To calculate the horizontal tail volume coefficient ($\overline{V}_H$) the method used in industry is to plot a "notch" chart (using the Lockheed term), or "scissors" plot (using Douglas terminology), (Fig. 7). Generation of the notch chart requires fairly detailed knowledge of aircraft geometry and associated aerodynamic forces, and cannot be expected of students in a one-semester course.

For horizontal tail sizing, the simplest method is to select a horizontal tail volume coefficient that is comparable with other aircraft in the same class.



Source: data from Schaufele

Figure 8: Estimation of $\overline{V}_H$

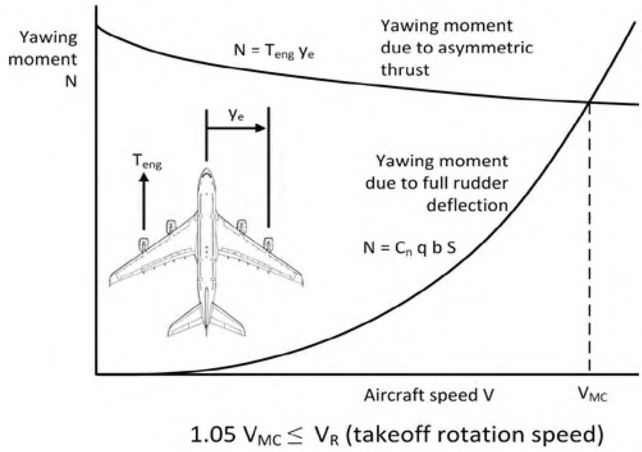


Figure 9: Calculation of V_{MC}

A slightly more accurate method is to use the correlation between horizontal tail volume coefficient per unit of c.g. travel$\left(\frac{\overline{V}_H}{\%MAC}\right)$ and the longitudinal fuselage volume parameter $\left(\frac{(W^2_{fus})(L_{fuse})}{S_W \bar{c}_W}\right)$ (Fig. 8), where W_{fus} is fuselage width, L_{fus} is fuselage length, S_W is reference wing area and $\bar{c}_W$ is the MAC. The correlation exists, but cause and effect is not obvious.

There is a similar hierarchy of methods for estimating the vertical tail volume coefficient ($\overline{V}_V$).

For a commercial aircraft the tail is often sized for meeting the FAR requirements for takeoff minimum control speed (V_{MC}) (Fig. 9). Students can check that $V_{MC} \leq 1.13 V_{SR}$(stall speed in the takeoff condition) (FAR 25.149(c)).

Detailed aileron sizing is usually left to a two- or three-semester course.

12 PERFORMANCE

A single equation relates required (T/W) vs. (W/S), at a given point in the mission, for level flight, climb, acceleration, or sustained turn.

$$\frac{T}{W} = q\frac{C_{D0}}{\left(\frac{W}{S}\right)} + \left[\left(\dot{\psi}\frac{V}{g}\right)^2 + 1\right]\frac{K}{q}\left(\frac{W}{S}\right) + \frac{P_S}{V} \quad (3)$$

where q is dynamic pressure, $C_{D0}$is zero-lift drag, $\dot{\psi}$ is sustained turn rate, V is true airspeed, K is induced drag factor, and P_S is required specific excess power. This equation is needed to add constraint curves to the constraint plot for military aircraft. Students must remember (but often forget) to factor input values of (W/S) from reference values, and factor output values of (T/W) to reference values. A separate equation is required for instantaneous turn rate.

Although of more interest to glider pilots, students should be aware of differences in speeds for gliding at the minimum sink rate and minimum sink angle.

For takeoff and landing, Schaufele provides the best procedure for detailed calculation of balanced field length, all-engine takeoff field length (and hence FAR field length), and landing field length for commercial aircraft. Raymer provides an empirical equation, taken from Torenbeek, to estimate balanced field length which usually also defines FAR field length. These methods provide a more accurate estimate than methods used in initial constraint analysis.

13 COSTS

For military aircraft life cycle cost (LFC) is the preferred method for comparing aircraft costs, and this is treated adequately in Raymer. For commercial aircraft, direct operating cost (DOC) is the preferred method. Through the 1970s and '80s a standardized method of calculating DOC, the Air Transportation Association 1967 (ATA '67) method, was used by both industry and airlines, but when its limitations (such as omission of capital costs) became increasing apparent, several different methods emerged, many of them proprietary.No standardized method has emerged.

An estimation method known as DOC+I (Direct Operating Cost plus Interest) is based on the work of Liebeck [10], who drew upon the operating costs of McDonnell Douglas airplanes in commercial service up until 1993, using data which reflect costs in a deregulated environment. The DOC+I method takes into account the following operating expenditures: fuel, flight crew, airframe maintenance, engine maintenance, landing fees, navigation fee (for international flights), depreciation, interest, and insurance. The equations can be adjusted to account for inflation. Students should be familiar with this or similar methods, but it is unlikely that time can be found to make use of it in a one-semester course.

14 CONCLUSIONS

A one-semester course in aircraft conceptual design can provide only a quick overview of the design process. Students will learn how each technical discipline contributes to the design, and how these technologies must be traded. Time constraints prevent detailed trade studies, but these studies are an important part of the design process. Design analysis is only one part of aircraft design. The design of an aerodynamically, structurally and operationally efficient aircraft is equally important.

REFERENCES

[1] D.P. Raymer, *Aircraft Design: A Conceptual Approach, 5th Edition*, AIAA, 2012.

[2] R.D. Schaufele, *The Elements of Aircraft Preliminary Design*, Aries Publications, 2007

[3] L.M. Nicolai, and G.E. Carichner, *Fundamentals of Aircraft and Airship Design, Vols. 1 and 2,* AIAA, 2011 and 2012.

[4] J. Roskam, *Airplane Design Parts I - VIII*, Roskam Aviation and Engineering Corp, 1985

[5] E. Torenbeek, *Synthesis of Subsonic Airplane Design*, Delft University Press, 1982

[6] R.S. Shevell, *Fundamental of Flight, 2nd Edition*, Prentice Hall, 1983

[7] E. Obert, *Aerodynamic Design of Transport Aircraft*, Delft University Press, 2009

[8] P.M. Sforza, *Commercial Airplane Design Principles*, Elsevier, 2014

[9] D.E. Hoak, et al., *The USAF Stability and Control DATCOM*, Air Force Wright Aeronautical Laboratories, TR-83-3048, 1960 (revised 1978)

[10] R.H. Liebeck, et al., *Advanced Subsonic Airplane Design and Economic Studies*, NASA CR-195443, 1995

THE ELECTRIC POWERED UAV DESIGN/BUILD/FLY PROJECT FOR UNDERGRADUATES AT NUAA

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Key words: Unmanned Air Vehicle, Design project, Design education, Teamwork.

Abstract: *This paper presents aircraft design education practice through a design/build/fly project of remote-controlled, electric powered unmanned air vehicles. The primary goal of the project is to have students gain insight into the processes of aircraft design and developments. The project covers conceptual design, preliminary design, detail design, fabrication, and flight tests of the electric powered unmanned air vehicle. The organization of student teams, instructors, and process-monitoring is critical for success of the project. Several examples of the project are illustrated. The observations to the project are concluded.*

1 INTRODUCTION

Since 2004, a design/build/fly project for remote-controlled, Electric-Powered, Unmanned Air Vehicles (EPUAVs) has been conducted at Nanjing University of Aeronautics and Astronautics (NUAA). The objectives of this project are to have the students gain insight into the processes of aircraft design and developments; to motivate the students to gain knowledge in areas including aerodynamics, structures, propulsion, flight dynamics, control and manufacture; to develop skills to solve engineering problems; and to cultivate engineering teamwork.

The project is oriented to seniors (forth year students) majoring in aircraft design and engineering, and is financially supported by the Teaching Affairs Office at NAUU[1]. Up to this point, more than 70 teams have participated in and completed the project. In this paper, the processes and organization of the project will be presented, several examples of the project will be illustrated, and, in conclusion, observations to the project will be offered.

2 PROJECT REQUIREMENTS AND PROCESS

The tasks of the project are: 1) the student team must develop a design for a remote-controlled, Electric-Powered Unmanned Air Vehicle (EPUAV); 2) the student team must finish the fabrication of the EPUAV; 3) a flight test must be demonstrated.

The basic requirements for the EPUAV are: 1) the maximum size of the EPUAV is no larger than 2.5m due to transportation limitations; 2) the cost of the EPUAV fabrication is less than ￥4000 due to the limited budget; 3) the team should determine the design concept of the EPUAV and its design requirements; 4) the EPUAV project should be finished within 18 weeks.

The project is divided into six phases: 1) conceptual design, 2) preliminary design, 3）detail design, 4）fabrication, 5）flight tests, and 6) documentation and presentation.

1) Conceptual Design

In the conceptual design phase, the major works are: (1) determining the EPUAV overall configuration; (2) designing the fuselage configuration, wing configuration, empennage configuration, control surface configuration and landing gear layout; (3) selecting a propulsion system; (4) evaluating the design concept through the aerodynamics, propulsion, weights, performance, and stability analysis using rapid engineering methods.

Students should complete the conceptual design by the use of software and tools. For example: the CAD software CATIA is used to generate the aircraft configuration, and the program AVL[2] (a code based on vortex lattice method) and Friction[3] (a code predicting zero-lift drag) are used to evaluate the aerodynamic performance.

Usually, the conceptual design phase needs 3 weeks. The primary outputs of conceptual design phase are a 3D model of the aircraft configuration, and a document on feasibility of meeting the requirements with evaluation results for the design concept. A typical 3D model of the aircraft configuration from the project in 2016 is shown as in Fig.1.

Figure 1: 3D model of aircraft configuration in conceptual design phase

2) Preliminary Design

In the preliminary design phase, the aircraft configuration from conceptual design phase is evaluated by a more detailed method. The aerodynamic performance is evaluated by the panel method or other CFD software. Figure 2 is an example of aerodynamic modeling by the panel method[4]. Based on the more detailed evaluation results, the configuration is refined to improve the aerodynamic performance.

The internal and structural layout of aircraft is developed by use of CATIA during the preliminary design phase. The structural materials are selected and the structural components are sized, based on past experience.

The structural weight prediction of aircraft is refined using CATIA. The more detailed flight performance and stability characteristics are evaluated using the refined aerodynamic and weight data.

The preliminary design phase usually needs 4 weeks. The primary outputs of preliminary design phase are 3D models of the refined aircraft configuration, and internal and structural layout, plus a document that guarantees the design requirements are met. A typical geometric model of the internal and structural layout is shown in figure 3.

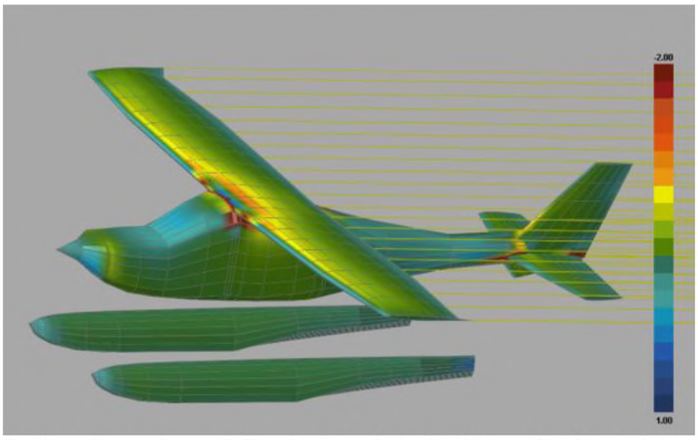


Figure 2: Aerodynamic modeling by panel method in preliminary design phase

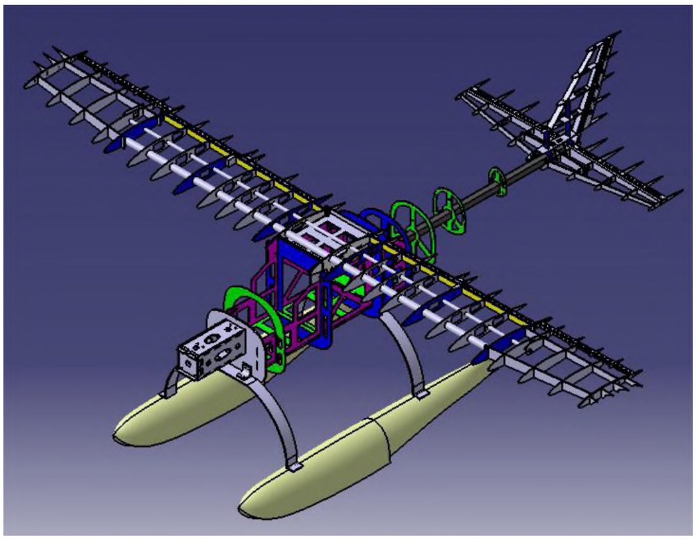


Figure 3: Geometric model of internal and structural layout

3）Detail Design

In the detail design phase, all parts of the structure are designed based on the structural layout from the preliminary design phase. The primary loads are determined and the stress and deformation of the overall structure are predicated using MSC.Patran software. The designs for the major connecting parts of the structure are refined to make sure that the parts have enough stress. The control systems that control the motor, rudder, elevator, ailerons and landing gear are designed.

Usually, the detail design phase needs 5 weeks. The outputs of the detail design phase are the drawings of all parts and the control system. Figure 4 is an example of parts design and stress analysis.

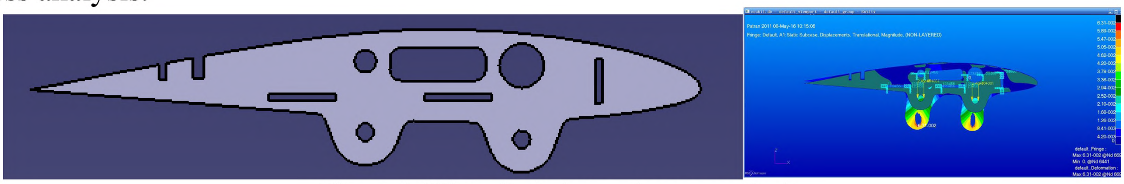


Figure 4: Wing rib design and stress analysis.

4）Fabrication

All parts are fabricated and assembled into the components in the NUAA fabrication lab or in the cooperative factory by the team. The facility, such as laser cutting machine, drill and others are provided in the fabrication lab. Figure 5 shows students fabricating a mould for the fuselage skin, and assembling the wing and fuselage in the fabrication lab. The fabrication of the EPUAV usually takes four weeks.

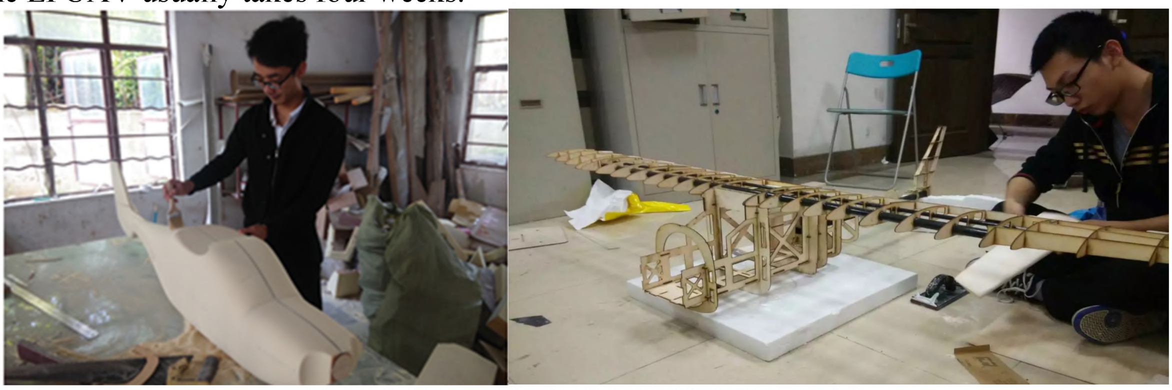


Figure 5: Students fabricating the EPUAV in the lab

5）Flight tests

After finishing the fabrication of the EPUAV, students can begin to test their vehicle. The tests include: 1) propulsion system test, 2) control system test, 3) ground taxi test; 4) flight test.

Figure 6 shows students conducting the ground test of the EPUAV.

Figure 7 shows the flight test of the EPUAV.

The tests of the EPUAV usually take two weeks.

6）Documentation and Presentation

After finishing the flight tests, students must write a report on the processes and their achievements of the project. Also, a final presentation of the project must be delivered by each team to the instructors and the other students. The grade for each student is determined by the team achievement, individual contribution and attendance.

Figure 6: Taxi test of the EPUAV on the lake at NUAA campus

Figure 7: Flight test of the EPUAV

3 ORGANIZATION OF THE PROJECT

The EPUAV project is challenging for students, and a large amount of work must be completed in 18 weeks. Therefore, organization is critical for success of the project.

1) Teams

Each year around five teams participate in and complete the project. Each team usually consists of five or six students. A team leader is responsible for organizing the weekly team meeting, and coordinating the teamwork. Each student is responsible for a specific discipline, such as aerodynamics, structures, propulsion, stability and control. Each team should have weekly meetings to discuss current accomplishments, to make decisions about specific problems, and plan the next steps. All members should participate in the discussions at each team meeting. Every member is equally responsible for the team's progress and success.

2) Instructors

The EPUAV project is directed by a group of instructors, who are specialized in different disciplines, such as aerodynamics, structures, propulsion, stability and control. During the project, the instructors give a series of lectures on each phase of the project; for example: an overall project plan, conceptual design method, aerodynamic analysis method, and application of structural analysis software.

A group of teaching assistants (graduate students) also play an important role in assisting in use of the software and fabrication of the EPUAV.

3) Project monitoring

In order to complete the EPUAV project within the limited time, project monitoring is necessary. Each team must submit a report detailing their weekly progress after which the instructors can discuss the designs with the teams, and give them advice and guidance.

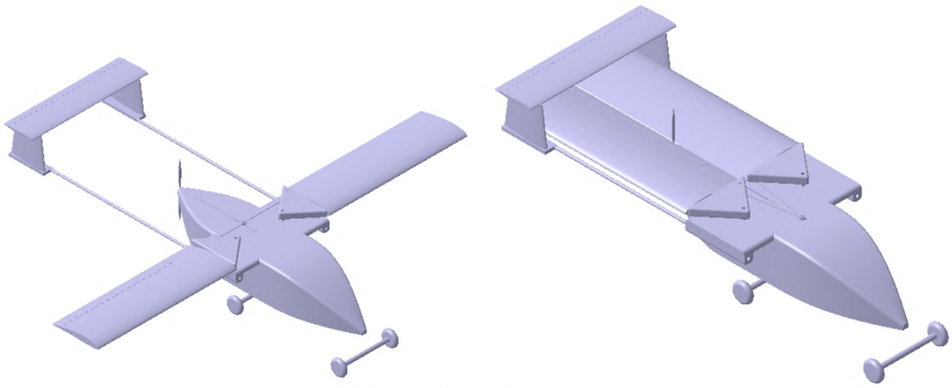
The results of the conceptual design, preliminary design and detail design must be presented in a critical design review meeting to the instructors and all teams.

4 EXAMPLES OF THE PROJECTS

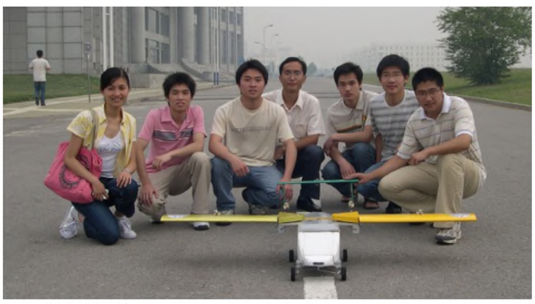
More than 70 teams have participated and completed the EPUAV project since 2004. Various EPUAV concepts are designed, fabricated and tested. The following are a few examples of previous EPUAV projects.

1) Flying car

In 2007, a team proposed a flying car design concept as shown in figure 8. This project was quite challenging, especially for the design of the propulsion system which needed to drive the wheels when in car mode and the propeller when in aircraft mode. The team successfully completed the design, fabrication and tests of the flying car model. The tests showed that the flying car model could run on road like a car, and could fly like an aircraft.



(a) Configuration of the flying car

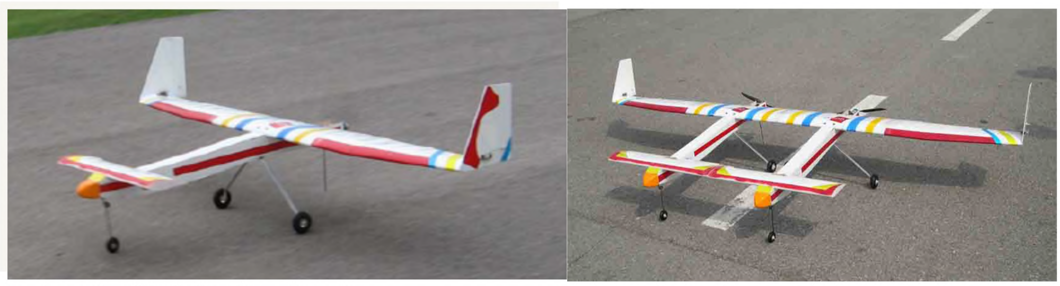


(b) Structual layout of the flying car (c) Team members and their flying car model

Figure 8: Flying car project

2) Modular aircraft concept

In 2007, a team proposed a modular aircraft concept. The fundamental theory is that two basic aircraft can be connected to produce a new large aircraft (derivative aircraft). In this way, a family of aircraft for different missions can be produced with low cost. The configuration of the basic aircraft is a canard configuration aircraft as shown in 9(a). The team built two of the basic aircraft, and then connected the two together to obtain a derivative aircraft which has a canard, double fuselage configuration as shown in 9(b). This derivative aircraft has new performance with longer endurance and larger payload. The flight tests showed that both the basic aircraft and the derivative aircraft had good stability and control characteristics.



(a) basic aircraft (b) derivative aircraft

Figure 9: The modular concept EPUAV

3) BWB aircraft project

Aircraft designers are becoming increasingly interested in the Blended Wing Body (BWB) configuration due to its higher aerodynamic efficiency. But the stability and control characteristics of BWB configuration had not been fully explored. In 2011, a team tried to study the stability and control characteristics of the BWB concept by constructing a BWB model aircraft. They built the BWB model aircraft as shown in figure 10, and finished several flight tests. From this project, the students realized that the prediction accuracy of the center of gravity (C.G.) and aerodynamic center (A.C.) during the preliminary design of the BWB model aircraft are crucial for its stability and control. Also, special attention should be paid to the the control surface layout design od this type of aircraft. The flight tests showed that the BWB model aircraft could attain good stability and control characteristics after the team adjusted the center of gravity and modified the control surface layout.

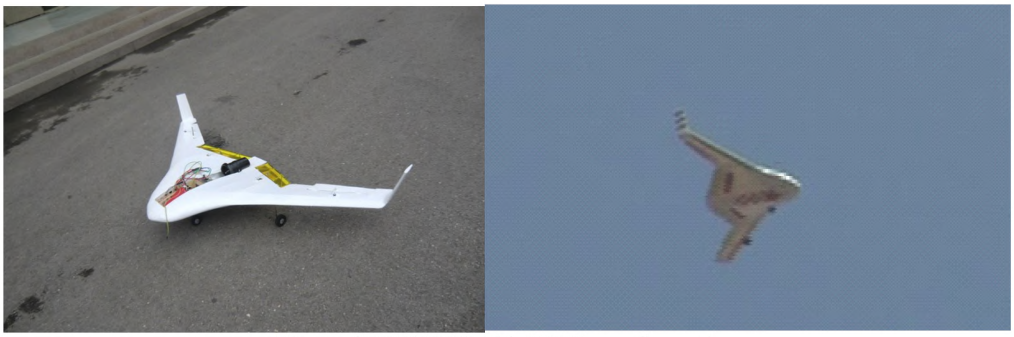


Figure 9: EPUAV with BWB configuration

4) Joined-wing aircraft project

The joined-wing configuration is another interesting unconventional concept that has advantages in terms of wing structural stiffness. In 2015, a team proposed a joined-wing configuration aircraft concept for future civil transport, and built a scaled model aircraft. They used aerodynamic analysis software to investigate the aerodynamic interference between the front-wing and aft-wing, and stability and control characteristics of the joined-wing configuration. During flight test, the pilot said that it was very easy to fly the joined-wing model, and it was much like flying a model aircraft with a conventional wing configuration.

Figure 10: The EPUAV with joined-wing configuration

5 OBSERVATIONS

Several important observations have been obtained from the EPUAV project during last 12 years.

1) Students have been motivated by the project to learn about aircraft design. By taking part in the project, students not only learn to design an aircraft on paper, but they also build and fly the aircraft that they have designed. Almost all of the teams try their best to complete the project to exhibit their ability. The students have to gain knowledge in disciplines such as aerodynamics, structures, propulsion, flight dynamics, control and manufacture during the project. The instructors find that some students might take more effort and volunteer more time than the instructors expected.

2) The project has motivated student innovation. Most of the teams try to design a new or different EPUAV. Some team are successful, but some teams are not, but either way, involvement in the project inspired the students to try new ideas and methods.

3) Through the project students have gained better understanding on the process of aircraft design and developments. All of the teams have completed the whole process including conceptual design, preliminary design, detail design, fabrication, and flight tests. Many students said that this experience was unforgettable and that it helped them to gain insight into the process of aircraft design and developments.

4) The students' skills solving engineering problems were developed during the project. The students encountered various unexpected problems that they could not find the answers to from their books. They had to find a way to solve the problems by themselves.

5) Teamwork has been cultivated during the project. The EPUAV project is quite challenging for the students, and a lot of work must be completed in 18 weeks. They had to learn how hold the weekly meetings to allocate the workload to the different team members, to discuss the problems they encountered, to make decisions for the design and plan for next step. At beginning of the project, students found some difficulties in teamwork. But after a few weeks, the teams worked well together. They realized that project should be well organized, and that teamwork was key factor for project success.

6) The students gained skills using industry-level software. During the project, students learned how to use the professional software such as CATIA, MSC.Patran and CFD. These programs were used extensively in the design and analysis of the EPUAVs. We found that most students were skillful in the use of CAD software CATIA. These skills will be very useful for the students to pursue a career in the aircraft industry.

6 SUMMARY

We have carried out the EPUAV projects for more than a decade. The project is quite challenging for students, and its process is complex. The organization of student teams, instructors, and process monitoring is critical for the success of the project. The feedback from students is quite encouraging. Most of the students said that they benefited greatly from the project. Our observations showed that the practice of the EPUAV project had fullfilled the objectives of aircraft design education.

REFERENCES

[1] X. Yu. *Senior Design Projects Aimed to Integration, Innovation and Practice*. Journal of Nanjing University of Aeronautics & Astronautics (Social Science Edition), 2008 (in Chinese).

[2] *http://web.mit.edu/drela/Public/web/avl/*

[3]*http://www.dept.aoe.vt.edu/~mason/Mason_f/FRICTman.pdf*

[4] *https://www.meil.pw.edu.pl/add/ADD/Teaching/Software/PANUKL*

A COMPLEX OF LABORATORIES FOR PRACTICAL TRAINING OF STUDENTS IN COMPOSITE TECHNOLOGY

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Key words: composite technology, educational and scientific complex, laboratory equipment

Abstract. *Described is an experience of the establishment and operation of the complex of laboratories for research and students training in composite technology as well as advanced training of industrial employees. Presented are structure and equipment of the complex.*

INTRODUCTION

The Aircraft Manufacturing Department of Kazan National Research Technical University named after A.N. Tupolev offers a program in Design and Production of Composite Parts.

During studies, it is critical to develop practical skills in the domain of composite technology. It is well-known that the application of theory in production of a specific part is the best way to master any discipline. Practical work aimed at manufacturing of specific parts, is the strongest stimulus for creative thinking. If a student obtains practical results that exceed existing design and technology, he or she gets enthusiastic about his or her profession. One may assume with confidence that this student will become a good professional.

Obviously, the most efficient education scheme would be the one which includes a final project featuring a practical section based on production of a composite part.

STRUCTURE OF EDUCATION CENTER

The structure and equipment of the complex of education laboratories at the Aircraft Manufacturing Department is based on the following concepts:

a) Laboratory equipment should cover the main stages of composite parts design and production. To some extent, this structure should look like a small-scale R&D enterprise. Due to the specific character of composite technology and the subject being taught, it is reasonable to have the following laboratories:

- Computer design and simulation;
- Material science;
- Tooling manufacturing
- Preforms production
- Molding

- Quality control
- Assembly
- Coating
- Equipment manufacturing and adjustment
- A class of well-known design and technological solutions for composite parts and tooling

b) Laboratories should ensure training of students with various levels of previous education:

- Students who have just started becoming familiar with specific subjects using simple and clear technology examples.
- Students who are doing their graduation project and developing innovative structures and processes.
- Industrial employees within an advanced training program.

c) The structure and equipment of the laboratories should meet the requirements of state-of-the art composite enterprise, and the cutting-edge technologies should be at the disposition of the laboratory.

d) Simulation and digital equipment control should be used at a maximum when processes are designed.

It is obvious that equipment and maintenance of such a laboratory complex requires significant funding. That is why the education center is based on a complex of laboratories of the Center of Composite Technology (CCT). Figure 1 illustrates the extensive structure of this research and education center.

A significant part of expenses for equipment maintenance and composite and auxiliary materials purchase are covered by the revenues from R&D under contracts with industrial partners.

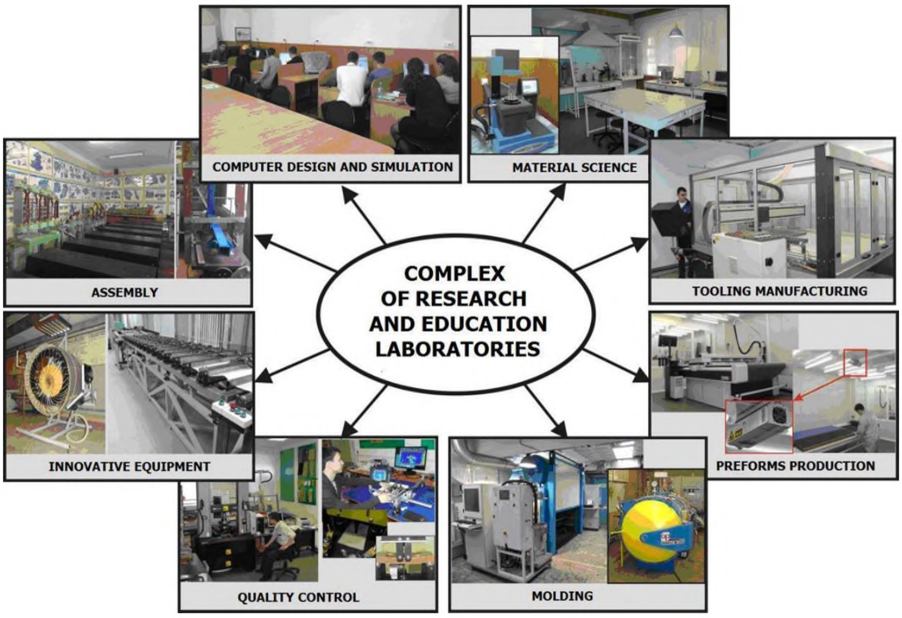

Figure 1: Structure of the United Research and Education Center.

LABORATORIES EQUIPMENT

Design and simulation lab (Figure 2) provides education in the following areas:

a) methods of 3D processing, tooling, and equipment development

b) writing of mechanical treatment control programs for NC units

c) writing of control programs for specific processing equipment, such as a cutter, a TFP machine, a radial braiding machine, etc.

d) development of ply book for processing package

e) development of injection scheme for transfer molding processes and simulation of injection process

f) structural analysis – calculation of deflection mode of composite structures

g) simulation to study production processes.

The laboratory is equipped with efficient high-end computers.

Siemens NX software is used for geometry design. Items b and c are realized in specific software. Items d and e are performed in FiberSIM and PAM RTM by ESI Group. Structural analysis (e) is done in ANSYS and NASTRAN.

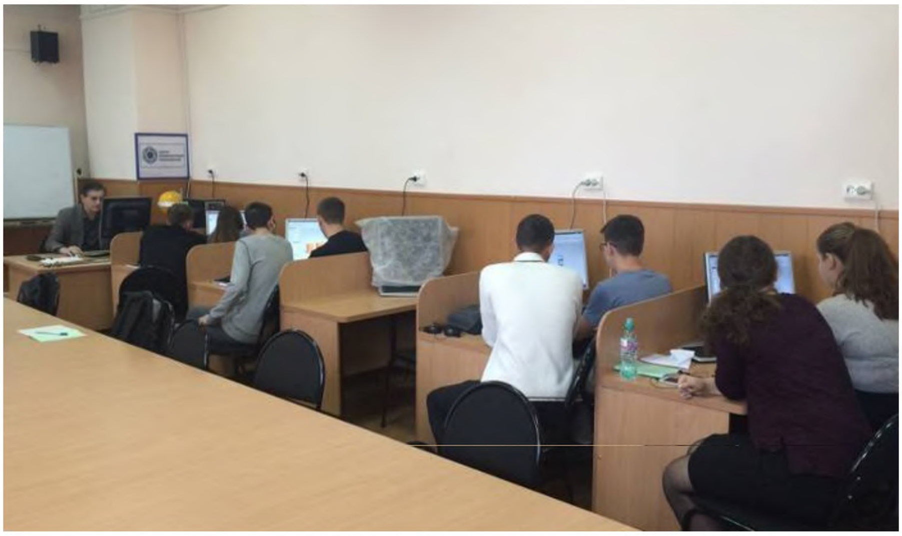

Figure 2: Laboratory of Computer Simulation.

Material science lab targets training in the domain of physics and chemistry of composites (Figure 3). It should have competences to study the properties of composites, generate new composites with given properties, develop and optimize modes of molding, including thermal compression, transfer and other methods of molding.

This lab is comprised of two parts: Chemistry Department, and Physics and Chemistry Department.

a

b

Figure 3: Material Science Lab:
a –Chemistry Department; *b* – Physics and Chemistry Department.

Chemistry Department has the standard equipment necessary to study polymers.

Physics and Chemistry Department is equipped with the following devices:

- Rheometer to study polymers' rheology
- Dynamic Mechanical Analyzer to study viscoelastic behavior of materials (elastic modulus) depending on various factors, such as temperature and load application frequencies
- Thermal Mechanical Analyzer to study changes in linear dimensions of material samples under controlled temperature, time, load and sample atmosphere.
- Differential Scanning Calorimeter to study physical and chemical processes in substances in the wide range of operation temperatures
- Optical Microscope
- Infrared Spectrometer to study chemistry of polymers.

Laboratory of Processing Tooling aims at development of knowledge and skills in methods and means of molding tooling production. This laboratory is equipped with NC units for mechanical treatment of different materials, such as metals, mold plastic, silicone, etc., and control and measurement equipment (Figure 4).

Figure 4: Laboratory of Processing Tooling Production.

Laboratory of preforms and pre-laminates production reflects the wide range of state-of-the-art methods for semi-finished net-shape parts production from dry materials and prepregs.

To illustrate the widely known layup preform production, a Zünd cutter and 3D laser projector are used. Layup is performed in a 'clean zone' with ISO grade 7, 8.

Innovative methods of preforms production are presented with the following equipment:

a) Tailored fiber placement machine (Figure 5) [1], [2]

b) Radial braiding complex based on HERZOG braiding machine (Figure 6)

c) Tufting and blindstitching complex for preforms manufacturing (Figure 7)

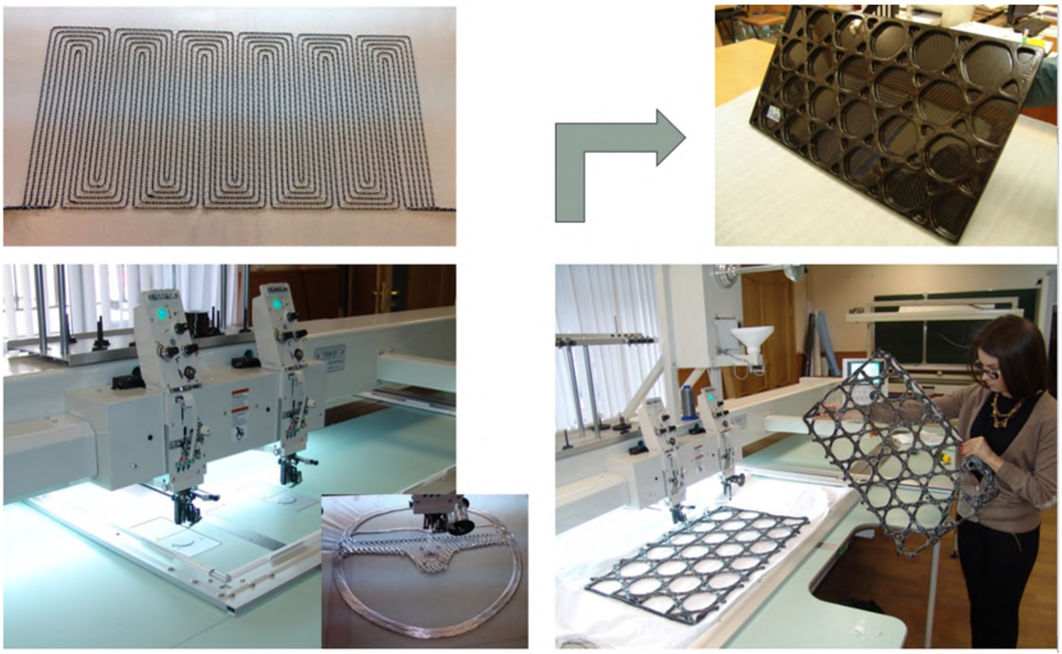

Figure 5: Tailored Fiber Placement machine (TFP).

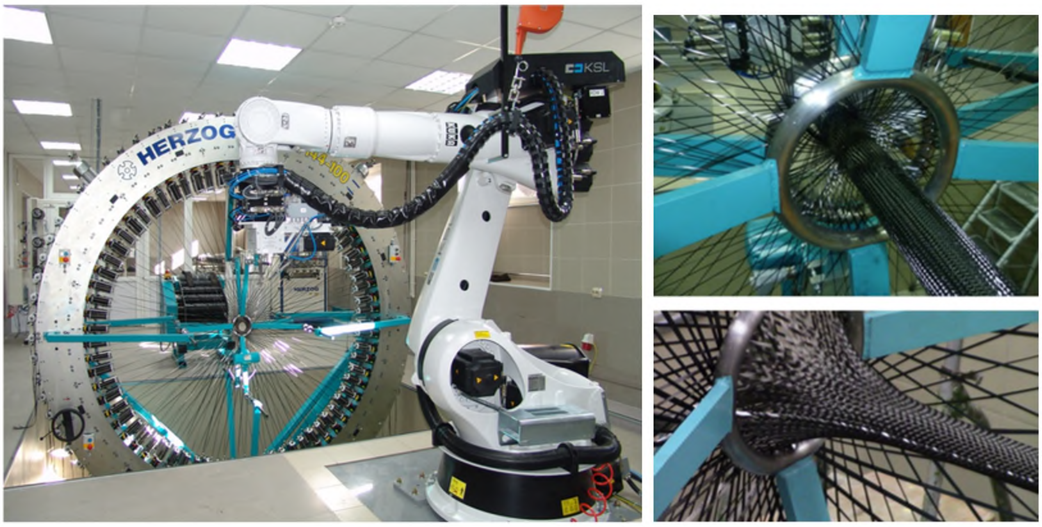

Figure 6: Radial Braiding Complex.

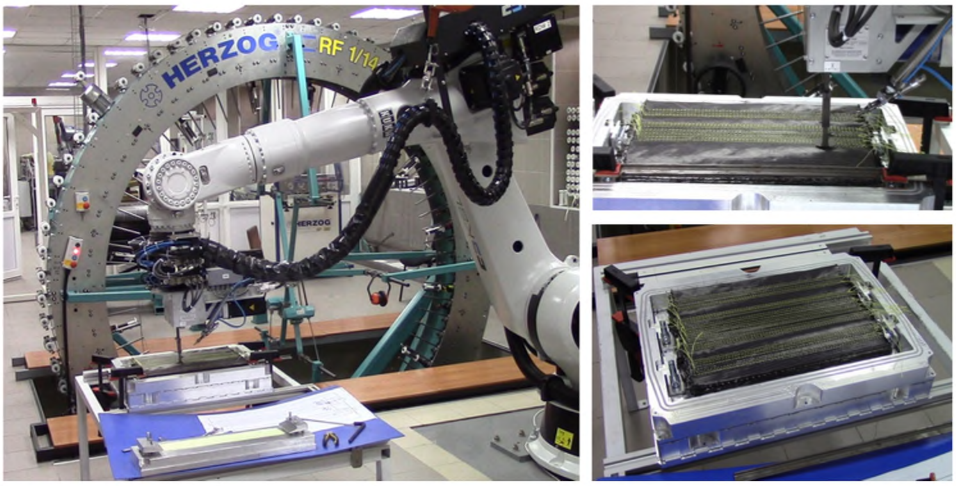

Figure 7: Tufting and Blindstitching Complex.

Laboratory of Molding consists of three departments.

In the first department, thermal compression methods are studied (Figure 8). The following equipment is used: small autoclave (Figure 8, *a*), hydraulic press (Figure 8, *b*), pneumatic press (Figure 8, *c*), vacuum press (Figure 8, *d*). In the second department, transfer molding is studied, including RTM (Resin Transfer Molding), Light RTM, RFI and infusion. Figure 9 shows two sets of equipment for RTM. In the third department, alternative molding processes are studied, in particular, studies involving a machine for ultra-violet curing. (Figure 10).

a *b*

Figure 8: Equipment for Thermal Compression Molding: *a* – Autoclave; *b* – Hydraulic Press; *c* – Pneumatic Press; *d* – Vacuum Press.

c *d*

Figure 8 (*cont'd*): Equipment for Thermal Compression Molding: *a* – Autoclave; *b* – Hydraulic Press; *c* – Pneumatic Press; *d* – Vacuum Press.

Figure 9: Complex for RTM.

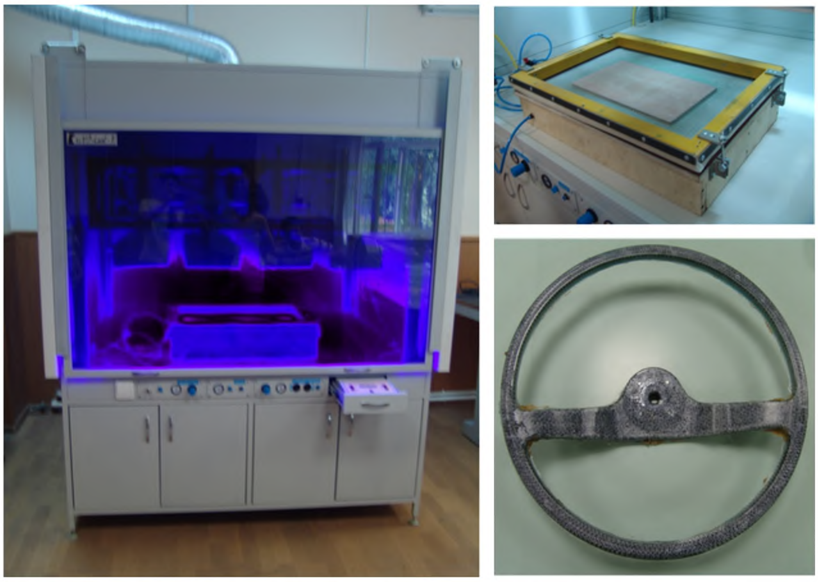

Figure 10: Machine for Ultra-Violet Curing.

Analytic equipment developed and produced by Inasco is used to study transfer molding and real-time monitoring of composite parts production based on material states. (Figure 11).

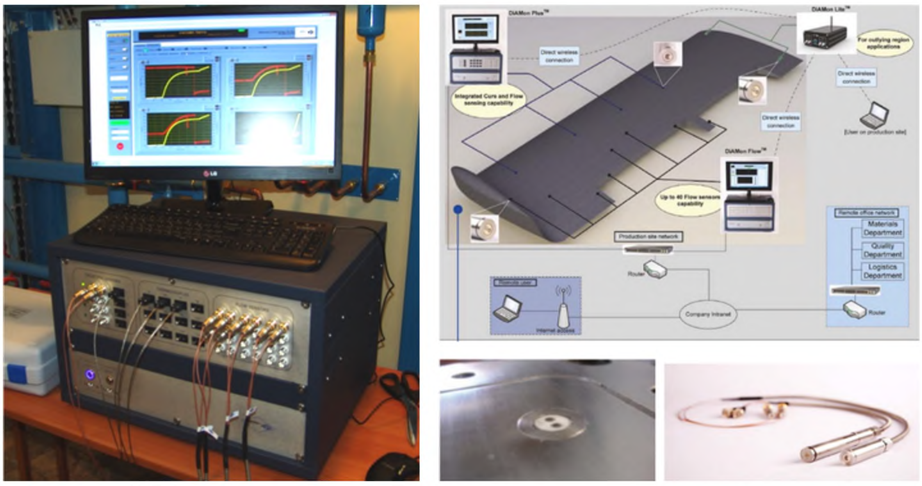

Figure 11: Machine to Study Resin Flow in a Preform.

Quality control laboratory includes four departments: parts and tooling geometry control, material quality control, static testing and impact testing.

To control parts and tooling geometry, an arm-type control and measurement machine is necessary. It may work either in contact or in scanner mode (Figure 12).

Material quality control is performed with an Omniscan MX2 ultrasound inspection machine (Figure 13).

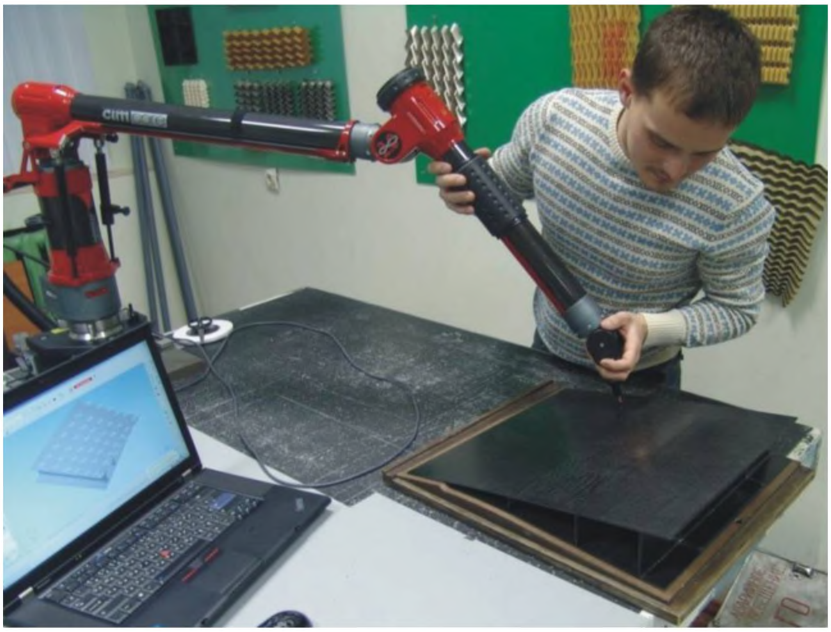

Figure 12: Control and Measurement Machine.

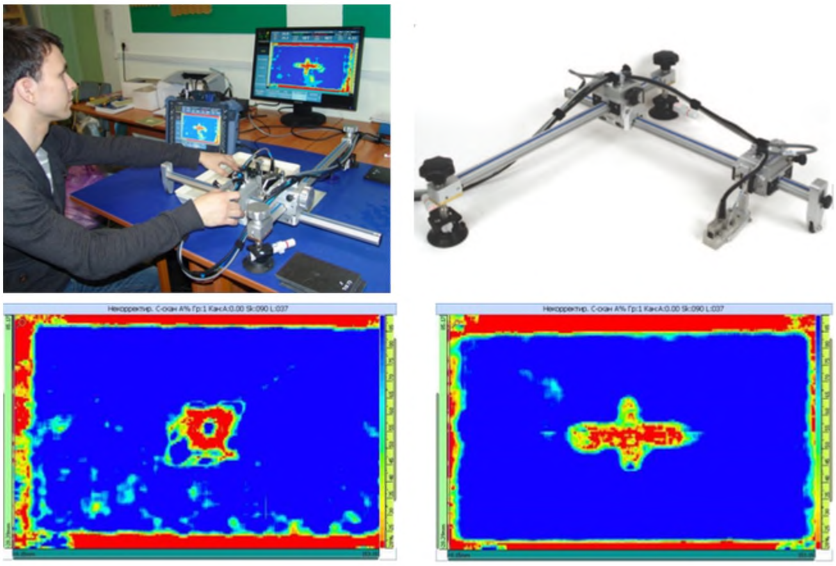

Figure 13: Non-Destructive Inspection of Composites.

To study static testing methods, a universal electrical mechanical machine, climate chamber and a set of testing tooling are used (Figure 14).

Figure 14: Tooling and Machine for Static Strength Testing.

Figure 15 demonstrates equipment that is used to study impact resistance and durability. The set includes a vertical impact machine, a pendulum machine and testing tooling.

Figure 15: Equipment for Impact Testing.

Assembly and joining lab (Figure 16) is arranged to study methods of thin-walled composite parts location, methods of reconciliation of dimensions and accuracy ensuring, as well as creation of mechanical and adhesive joints. This laboratory is equipped with stocks for location and assembly of two- and three-dimensional units. These units contain truss and shell composite elements. Specific tooling and instruments are used to study assembly methods.


Figure 16: Assembly Lab.

Laboratory of equipment production and adjustment (Figure 17) provides the basis for implementation of creative initiative of students and research assistants.

Under supervision of faculty staff, scientific and technical ideas that are born while working on graduate projects and theses find their way here [3].


Figure 17: Laboratory of Innovative Equipment.

SUMMARY

1. The aforementioned complex of laboratories:

– provides students with practical skills in composite parts production

– gets students familiar with processing equipment, and operating as well as programming of this equipment

– provides conditions for scientific and technical creativity.

2. This complex of laboratories unites the main industrial processing methods. At the same time, it does not cover a range of technologies, such as winding, pultrusion, spraying and methods of thermoplastic composites processing. Thus, a cooperation of universities that are mutually complimentary when it comes to equipment and processes seems to be reasonable. This lack may be compensated for by cooperation implemented within a network education system or training in an industrial enterprise that has the necessary equipment.

3. Operation of the complex is possible only when it is combined with R&D center that has revenues to cover the major expenses of training.

4. Key element for fully-fledged operation of training labs is academic literature that includes books, manuals for practical training sessions, project tasks, etc.

5. Methodology of the center should include a set of topics for prospective graduate projects. These topics should meet the requirements of a composite technology long-term development strategy.

REFERENCES

[1] Khaliulin, V.I., Khilov, P.A., Toroptsova, D.M. Prospects of Applying the Tailored Fiber Placement (TFP) Technology for Manufacture of Composite Aircraft Parts. Russian Aeronautics, vol. 58, No. 4, 2015, pp. 495 – 500.

[2] Mattheij, P., Gliesche, K., Feltin, D. Tailored Fiber Placement-Mechanical Properties and Applications. Journal of Reinforced Plastics and Composites, vol. 17, no. 9, 1998, pp. 774-786.

[3] Khaliulin, V.I., Razdaibedin, A.A. Determination of Processing Parameters for the Folded Core with Enveloping Curvilinear Surface. Russian Aeronautics, vol. 58, No. 1, 2015, pp. 88-96.

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COMPLEX FOR EDUCATION AND TRAINING IN COMPOSITE PARTS PRODUCTION

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Keywords: education, polymer composite materials, RTM, infusion, contact molding.

Abstract. *Developed is a complex for education and training in the field of composite parts production involving such methods as contact molding, infusion and modified resin transfer molding (RTM) using a tooling with integrated resin injection system, methodologically and financially adapted to learning process.*

1 INTRODUCTION

Nowadays technology development involves vast composites application. First, composites were applied in transport, where weight is critical. As a result, more than 50% of the structure of certain aircraft is made up of composites. Composites have become a common material in construction, sports and everyday life.

Traditionally, training for the students to get practical and production skills is based on the treatment of woods and metals. So there is a gap in composite technology training and education. Considering the fact that technical advances and improvements are closely related to the application of composites, development of knowledge and skills in composite technology becomes more and more topical.

Equipment and manuals for training and education in composite technology differ significantly from the ones necessary for metal and wood treatment training. Thus, the introduction of production complexes in education and training process may be considered reasonable, so that the student can get general knowledge about methods of composite parts production.

The establishment of an educational molding complex for the students to get practical skills in production of composite structures is suggested. A suitable configuration for this complex would one as typically found in large-scale composite production.

The complex should be adapted to fit most educational and training processes, and equipped with machinery, tooling and instruments for composite parts production to ensure mastering the main steps of this process.

An idea to create such a complex is based on common processes of composite parts production by contact molding, dry preform layup followed by infusion and RTM. It is suggested to use carbon fabric and two types of resins – for cold and hot cure.

Industrial variants of RTM involve costly equipment and numerical control systems that are unacceptable in the educational environment. So, there is a need for an analogue that would provide students with knowledge on the basics of the technology and a possibility to give a way to their creative potential using modified, less expensive equipment. This research provides a variant of such a patentable RTM process solution.

This technology is well adapted to small-scale and middle-scale production. If one has to produce 500 – 20 000 parts per year, RTM provides maximum optimization of costs and improvement of product quality [1]. If one has to produce one or a few parts, production costs rise in the order of magnitude and become equal to the cost of equipment itself. The most costly and complex part of the RTM process is injection machine, the one that injects resin into the tooling. In order to decrease the costs of single part manufacturing, it is suggested to give up a complex and expensive injection machine and use a simple resin injection system instead. This system is based on a material that increases its volume at a phase change from solid to liquid state at a certain melting temperature programmed in the material.

2 TOOLING WITH INTEGRATED RESIN INJECTION SYSTEM

The scientific novelty here is the development of a transfer molding process using tooling with an integrated resin injection system for composite parts manufacturing. Injection is based on a physical process of instant expansion of a substance due to phase change (from solid to liquid) under heating. There is also a possibility to program phase change initiation temperature.

The principle of the injection system operation is as follows. There is a specific cavity in the tooling that contains a substance with a high programmed coefficient of thermal expansion. There is a membrane next to it, and then comes the second cavity with resin. There is a channel in the upper cavity that is connected to the tooling. When tooling is heated, the substance starts to expand and pushes the membrane. The membrane starts to push the resin out of the upper cavity into the tooling and into the preform (see Figure 1). the method of resin injection, described in [2], is significantly different – the pressure is created by compressed air.

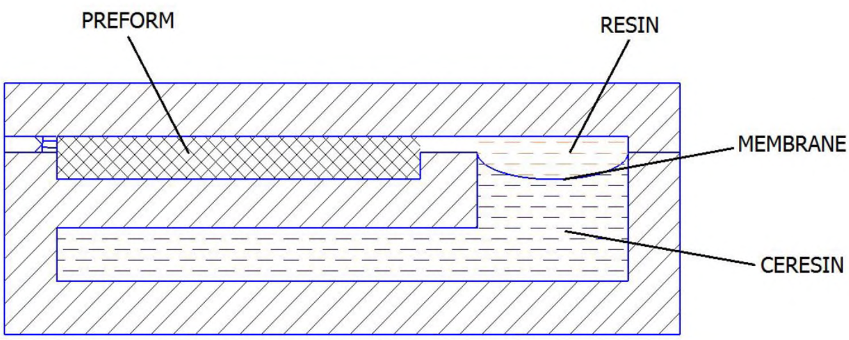

Figure 1: Structure of Tooling with Integrated Resin Injection System

Ceresin wax ‘Ceresin 100’ is used as an expandable substance in the tooling [3]. Unlike other expandable elements, ceresin wax expands progressively, and maximum expansion takes place at the moment of phase change (from solid to liquid). This is exactly the type of expansion necessary for correct operation of the tooling, because the resin should be injected at a certain temperature at a precise moment (Figure 2).

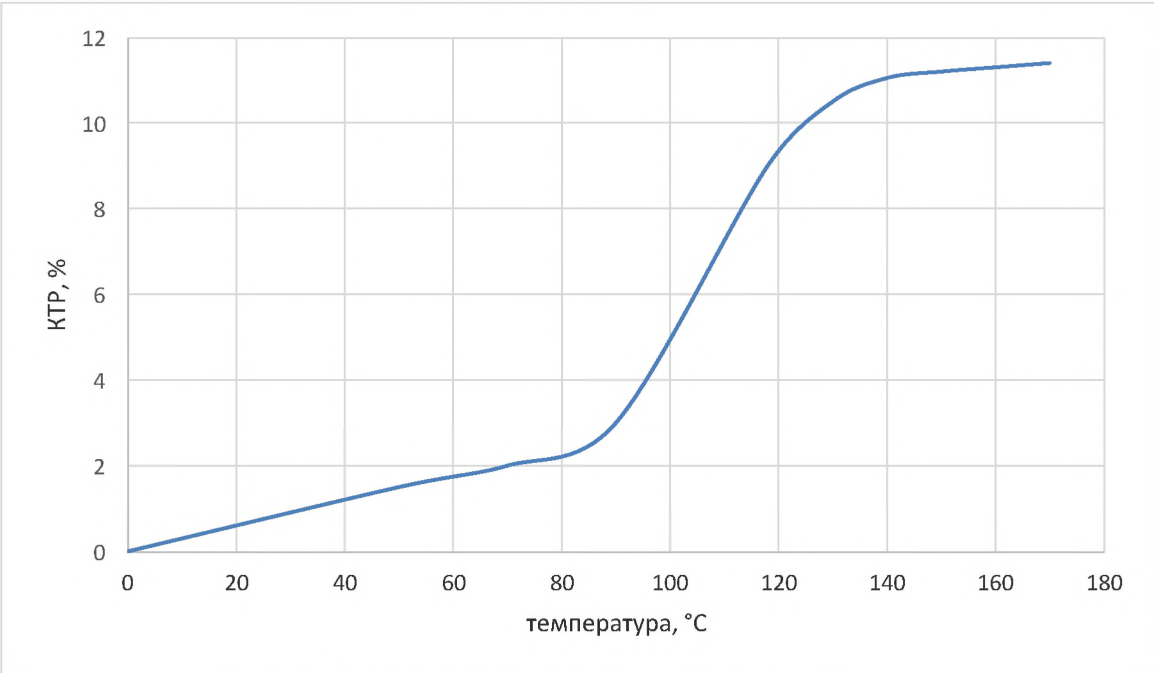

Figure 1: Thermal Expansion of Ceresin 100 wax.

Ceresin 100 melts at 116°C, this is the temperature of resin injection.

the coefficient of ceresin expansion was determined experimentally. Ceresin was heated up to melting temperature and its volume was measured. Then it was cooled down to room temperature and the volume was measured again. Further, a ratio between the difference of the volumes and ceresin wax volume at a room temperature was determined. The coefficient of thermal expansion α is as follows:

$$\alpha = 3{,}5/46{,}5 * 100\% = 7{,}6\% \sim 8\%$$

So, when heated till melting temperature, ceresin wax expands by 8% of the initial volume. Thus, a conclusion can be made that with ceresin wax we can push out the volume of resin which equals to 8% of ceresin wax volume.

Dimensions of the plate being produced are 200 x 40x 3 mm. The volume of the plate is as follows:

$$V_0=200 * 40* 3 = 24\ 000\ mm^3=24\ ml$$

Let's assume that fiber volume fraction would be 60%. Then the volume of resin necessary for plate production would be

$$V_c=(24-24*0{,}6) = 9{,}6\ ml$$

We multiply this value by safety coefficient k=2, because an excess of resin will get away via a drain channel and a lack of resin may lead to the experiment failing.

The coefficient of thermal expansion of Ceresin 100 is 8%. Volume of ceresin wax needed to push out necessary amount of resin is calculated as follows

$$V_u = (V_c*k)/б = (24-24*0{,}6) * 2/0{,}08 = 240\ ml,$$

where V_c is the required resin volume, k is the safety coefficient and $б$ is the coefficient of thermal expansion of Ceresin 100. Taking calculated parameters into consideration, a 3D model of a tooling was designed (Figure 3).

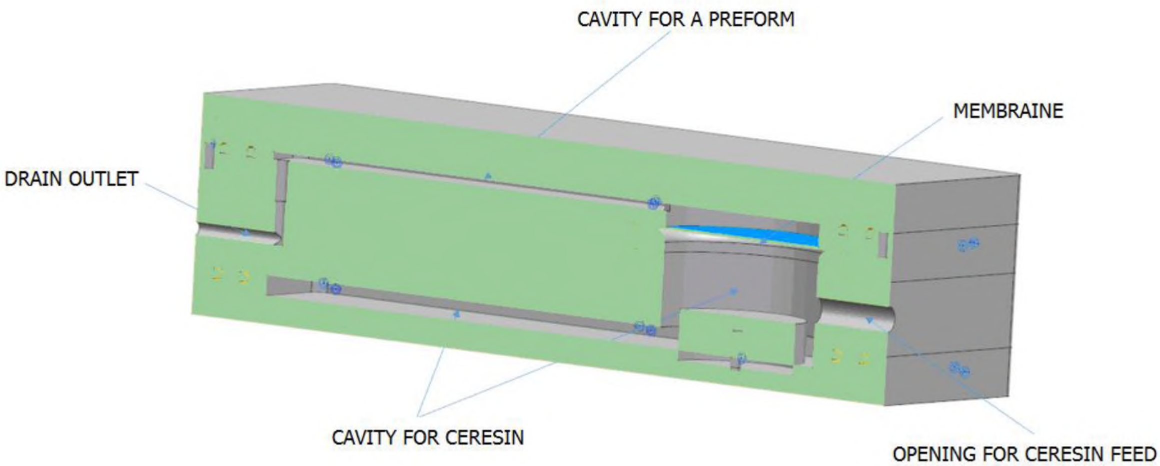

Figure 2: Model of RTM Tooling.

A few samples with stable dimensions were produced from carbon and RTM6 resin using this tooling. The thickness error is below 0,1 mm. A possibility to use this technology within an education and training complex for polymer composite parts manufacturing was proved experimentally.

3 EDUCATION AND TRAINING COMPLEX

Training is based on the production of various objects that present practical interest and visualization, including sports inventory, parts of transports and daily objects.

Basic objects are ready-to-use tooling for the production of the following:

1. Small-scale individual parts.
2. Pieces of sports inventory.
3. Parts of small-scale unmanned aircraft.

The complex consists of a few units. Each unit simulates processes and working methods. Cost and safety-wise, the equipment in the units is adapted to the educational process.

Taking into consideration the sequence of the processes, the main units of the complex are:

1. A table for cutting materials, equipped with electrical scissors and templates.
2. Molds for dry material layup to create a preform.
3. Contact molding unit.
4. Infusion machine and materials for technological package.
5. Patented tooling for modified RTM.
6. Oven or infrared lamps for curing under vacuum and temperature application.
7. Units for structures treatment equipped with jigger and grinding instruments to adjust the structure as well as scales and instrumentation for geometry control.
8. A multimedia unit.

Figure 4 demonstrates the visualization of the units.

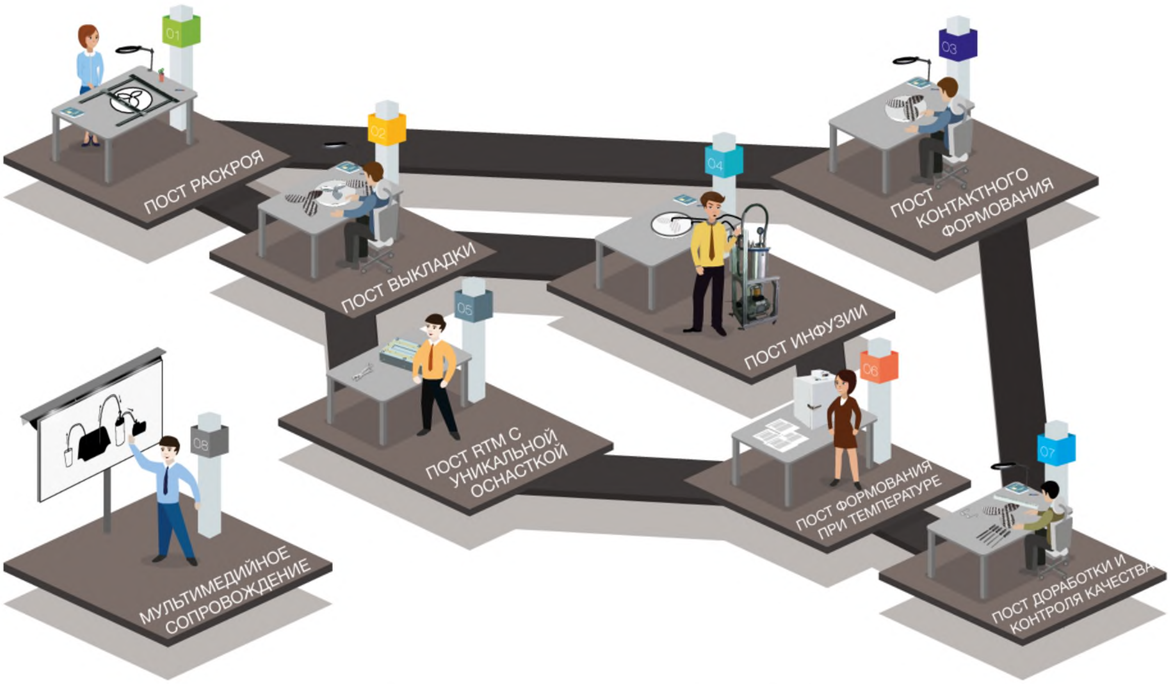

Figure 3: Model of Education and Training Complex.

The education and training complex has the following methodology materials:

1. A book about the basics of composite materials science, areas of application and composites processing.
2. Two-part practical manual: first part includes information about the complex, equipment and has a route operation process for part production; second part is a computer file with animation of operations.
3. A book of tasks for the students to choose a process and equipment for production of different composite parts and structures.

The engineering part of the process includes calculation and research to develop and determine process parameters and equipment. Those are:

1. Research and selection of composite material components that provide required mechanical and other properties of the part.
2. Calculation and optimization of layout for preforms of complex parts.
3. Calculation of the number of mono-layers in the part.
4. Selection of materials used in molding process.
5. Assessment of mold and structure compatibility based on coefficients of linear thermal expansion.
6. Calculation of injection and vacuum feed points for infusion and RTM.
7. Selection of the ways and means to control geometry and mechanical properties of composite parts.
8. Projects dedicated to the selection of equipment for production of new parts based on

suggested production processes.

9. Preparation of reports.

It is assumed that the students will prepare an essay, entitled ‘Selection and justification of a process’, for certain structures, selected from the book of tasks by the teacher.

4 SUMMARY

An education and training complex for production of polymer composite parts by contact molding, vacuum infusion and modified RTM using tooling with integrated resin injection system is developed within the scope of this research.

The tooling with integrated resin injection system is developed for resin transfer molding of composite parts without a need for an expensive injection machine. This solution provides a financially available method to teach basic principles of RTM with an innovative approach. This technology is cost-effective when it comes to small-scale production of prototyping using RTM.

The education and training complex aims to:

1. Teach students of innovative creativity centers, magnet schools, vocational schools and professional training classes in the industry, the basics of composite parts production.
2. Conduct mobile and stationary master-classes and demonstrations.
3. Establish small-scale production and prototyping facilities.

REFERENCES

[1] Patent № 5,306,448 (US), Int. Cl.5 B29C 43/10. Method for resin transfer molding process/Robert V. Kromrey; United Nechnologies Corp. – Appl. No.: 138,776; Filed: Dec. 28, 1987; Date of Patent: Apr. 26, 1994.

[2] Патент РФ № 2008123169/05, 09.11.2006. ЭБЕРТ Ульрих, ФРИЕДРИХ Мартин. ПРИСПОСОБЛЕНИЕ, СИСТЕМА И СПОСОБ ИЗГОТОВЛЕНИЯ КОМПОЗИТНЫХ КОМПОНЕНТОВ // Патент России № 2423237. 2009. Бюл. № 35. (Facility, system and method of composite parts production)

[3] Топлива, смазочные материалы, технические жидкости. Справочное изд., под ред. В. М. Школьникова, М., 1989, с. 407-08. (Fuels, lubricants and technical liquids)

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REVIEW OF SOME ASPECTS OF LAUNCH

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Key words: LV – Launch Vehicle; SLWT – Super Lightweight External; RSRM – Reusable Solid Rocket Motor.

Abstract. *This paper describes a number of aspects related to the recovery of individual elements of the launch vehicle. It also takes into consideration the economic feasibility of the operation. It emphasizes the importance of the influence factor of series production to assess the effectiveness of the use of reusable elements. To this purpose, the model used by the competitive environment in which the product competes with its analog counterpart upgraded with finite capacity on the market.*

1. Introduction

The choice of recovery of worked-out components of a launch vehicle (LV) represents a compromise between the economic feasibility and technical capabilities. Against a background of variety in the design and configuration of LVs, it is the cost of technical means and actions for recovery that causes us to consider a question on practicability to recover separate valuable components of an LV instead of the traditional recovery of stages and blocks. Three known ways of recovery correspond to the traditional LV division into stages and blocks: by launching over wings, by means of parachute, and landing on jet engines. The life cycle of the block reuse includes work on its restoration. This circumstance is significantly reflected in a choice of components which are reasonable to keep for further use. For example, the cryogenic fuel tanks are considered to be the most expensive LV components, about $30 million (1990 prices) is the cost of a liquid hydrogen tank from the Space Shuttle system, (LWT model) and $33.5 million for SLWT[1] model. From this perspective, the recovery of cryogenic fuel tanks looks justified. On the other hand, the restoration of cryogenic fuel tank requires the elimination of peelings of the internal heat-insulating coating which is a time-consuming operation. The recovery and restoration of SRM (SRB) and RSRM accelerators for the Space Shuttles are less expensive in relation to technological advances - the cost of manufacturing two accelerators was $64 million in 1983, but was estimated at $25 million in the 1990s [1]. In this regard, the various projects related to recovery of blocks "Ts" of "Energy" LV over the wings [2, 3] probably had high economic risks. It is possible to reduce these risks in some cases due to refusal of recovery of large rocket blocks by increasing the profitability of LV at the expense of reuse of separate LV components.

Strategy

It is necessary to note that the concept of profitability in relation to such a specific branch as rocket production requires a certain specification. The volume of production of serial products is defined not only by the cost and the quality of the product, but also by countermeasures of competitors. Therefore, the total efficiency of an LV as a product depends also on its compliance with the current state of the market.

Special characteristics of this market are as follows; first of all, the LVs fall into obviously expressed classes by tasks and masses of useful load. Secondly: in general, not more than 2 enterprises are involved in each class of LV. Under these conditions, there can be adequate assessment of LV profitability on the basis of the market duopoly model, as shown in [4, 5 and 6].

Let us describe the main ideas of this approach. According to [4], the functions of demand for LV options are described by the linear model of the differentiated duopoly:

$$q_1(\omega, p) = q_0 + a_1^{\omega}\omega_1 - b_1^{\omega}\omega_2 - a_1^{p}p_1 + b_1^{p}p_2 \qquad (1)$$
$$q_2(\omega, p) = q_0 + a_2^{\omega}\omega_2 - b_2^{\omega}\omega_1 - a_2^{p}p_2 + b_2^{p}p_1.$$

Here: q_0 –is the costs market capacity, the cost of i-Type LV, LV reliability of i-Type option, the factors $p_i a_i^{\omega}, b_i^{\omega}, a_i^{p}, b_i^{p}$ –are the sensitivity parameters of demand function in relation to the cost and reliability of the products [6].

In this model, the balanced cost and balanced reliability correspond to the case of demand and supply equilibrium. Product reliability is considered as the product cost control method. Then, γ –is the initial price of product release at initial level of reliability, and price velocity at reliability change. - ω_i.

Transition to repeated use of separate LV components–the catapult launching of control blocks, fuel tank or engines will be the following logical step after recovery of LV blocks. The exact choice of components depends on the particular LV type.

Let us apply the above described model for assessment of efficiency of LV components recovery. Then, instead of the competitive product, it is necessary to consider the same LV, but with separate, multiple-use components (option 1 - LV without recovery, option 2 – LV with reusable components). The type of component chosen for recovery is not specified yet.

The LV cost in the initial model was taken as equal to [6]:

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The LV cost in the initial model was taken as equal to [6]:

$$p_i = p_{i0} + \gamma\omega_i, \quad i = 1,2. \tag{2}$$

2.1. Let us introduce the following notations:

$$\begin{cases} A_i = a_i^{\omega} - \gamma a_i^{p} \\ D_i = \gamma(q_0 - a_i^{p} p_{i0} + b_i^{p} p_{j0}) + p_{i0} A_i \\ B_i = b_i^{\omega} - \gamma b_i^{p} \\ i = 1,2 \quad i \neq j, \end{cases} \tag{3}$$

The following expressions are developed for the values of equilibrium reliability

$$\omega_1^0 = \frac{2A_2D_1 + B_1D_2}{\gamma(4A_1A_2 - B_1B_2)} \tag{4a}$$

$$\omega_2^0 = \frac{2A_1D_2 + B_2D_1}{\gamma(4A_1A_2 - B_1B_2)} \tag{4b}$$

Expression (2) should be corrected for this case by presenting the initial cost in the form of costs, amount of recovered component, and remaining part of construction:

$$p_1 = p_{1c} + p_E + \gamma\omega_1^0 \tag{5}$$

Assume that LV modernization cost is *E*, and recovery component modernization cost Δp_E, then:

$$p_2 = p_{1c} + E + \frac{p_E + \Delta p_E}{N} + \gamma\omega_2^0 \tag{6}$$

Where *N* is the use ratio of recovery component. Therefore:

$$\Delta p_0 = p_{20} - p_{10} = E + \frac{\Delta p_E - (N-1)p_E}{N}. \tag{7}$$

The difference in the options cost:

$$\Delta p = p_2 - p_1 = \Delta p_0 + \gamma(\omega_2^0 - \omega_1^0). \tag{8}$$

In contrast to model [6] where the LVs of different manufacturers are in competition, in our case the options of one type of LV are compared with and without a system of component recovery. Then:

$$\begin{cases} A_1 = A_2 = A, \quad B_1 = B_2 = B, \quad D_2 = D + \Delta D \\ a_1^p = a_2^p = a^p, a_1^\omega = a_2^\omega = a^\omega, b_1^\omega = b_2^\omega = b^\omega, \; b_1^p = b_2^p = b^p, \end{cases} \tag{9}$$

Under the market equilibrium conditions, respectively:

$$\omega_2^0 - \omega_1^0 = \frac{\Delta D}{\gamma(2A+B)} \tag{10}$$

By applying (3) we shall find:

$$\Delta D = (A - \gamma(a^p + b^p))\Delta p_0 \tag{11}$$

Let us find the change in cost (8). Considering (7):

$$\Delta p = \left\{1 + \frac{(A - \gamma(a^p + b^p))}{(2A+B)}\right\}\left(E + \frac{\Delta p_E - (N-1)p_E}{N}\right) \tag{12}$$

This model can be considered as the cost estimation only without detailed analysis of particular LV technical characteristics. Let us, in this approximation, consider the effect from the introduction of a system of components recovery using the numeric values developed in [6] based on sales market analysis:

$$a^p = 2{,}3 \cdot 10^{-6}\frac{unit}{USD}, \qquad a^\omega = 4\,unit, \qquad b^\omega = 2\,unit, \; b^p = 1{,}11 \cdot 10^{-6}\frac{unit}{USD}, \qquad \gamma = 2 \cdot 10^6$$

Judging from the figures given in [6], the question is likely about an LV of the Soyuz Class. In contrast to [6], the cost here is expressed in $USD as the unit of currency. Assume that the resource of reusable components is equal to *N*. Then, the difference in price for a series of *N* products is as follows:

$$\Delta Q(N) = N\Delta p = \; 6{,}286\;(NE + \Delta p_E - (N-1)p_E) \tag{13}$$

Let us see the numerical example. If an RD-180 engine is the recovery component, then its estimated cost is $11 million USD. At the use ratio of $N = 4$ engine and recovery system cost estimation $E = 0{,}36p_E$, $\Delta p_E = 0{,}4p_E$, the cost-cutting of series will be $\Delta Q(N) =$ 12млн. $USD. This is approximately equivalent to 6% of the series cost, where the LV prime cost is $50 million USD.

The earned value is sufficiently sizeable to warrant consideration of the options of possible schemes of engine recovery.

Demonstration

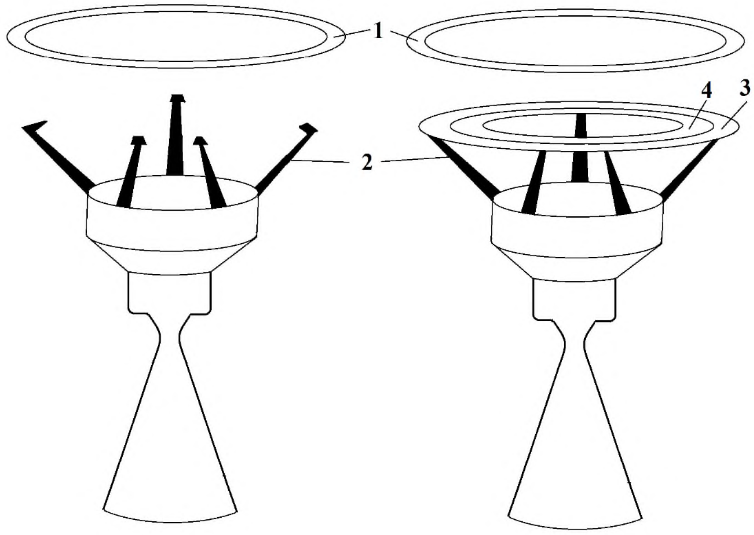
It is expedient to start consideration with the 1st stage engine unit as it is the most powerful in the LV, and its cost makes up an essential part of the whole stage cost. An engine recovery system can be defined in many respects by using the reserves which were already used or offered in the open press by the ways and components.

Fig.1 demonstrates the power scheme of the rocket engine gimbal. The engine thrust is transmitted through the truss elements [2] to the power belt which is a part of the LV.

To impliment the engine recovery system, it is suggested to insert an engine strong-ring to which the containers with parachutes are attached (Fig.1b). The engine is rigidly connected with the strong-ring through the truss gimbals.

In the course of recovery, the engine is blasted-off the LV at the point of contact of the strong-ring with the LV power belt. Engine stabilization and braking is provided by extraction parachutes. Deployment of the main parachute of 4360 sq.m in area takes place after the achievement of acceptable values of horizontal and vertical speed to provide a landing speed of 5-7m/s for the 7.3t weight of the engine assembly.

Characteristics of parachute system can be estimated by analysis of the existing parachute systems intended for landing freight which is of a similar weight, for example, the PBS-915 system ("Shelf-1"). At the same time, a cycle of operation and design of a parachute system for engine recovery has to consider a significantly high stabilization parachute-opening altitude and, therefore, more time of super aerodynamic flight, as well as the increased loads during the main parachute-opening phase.

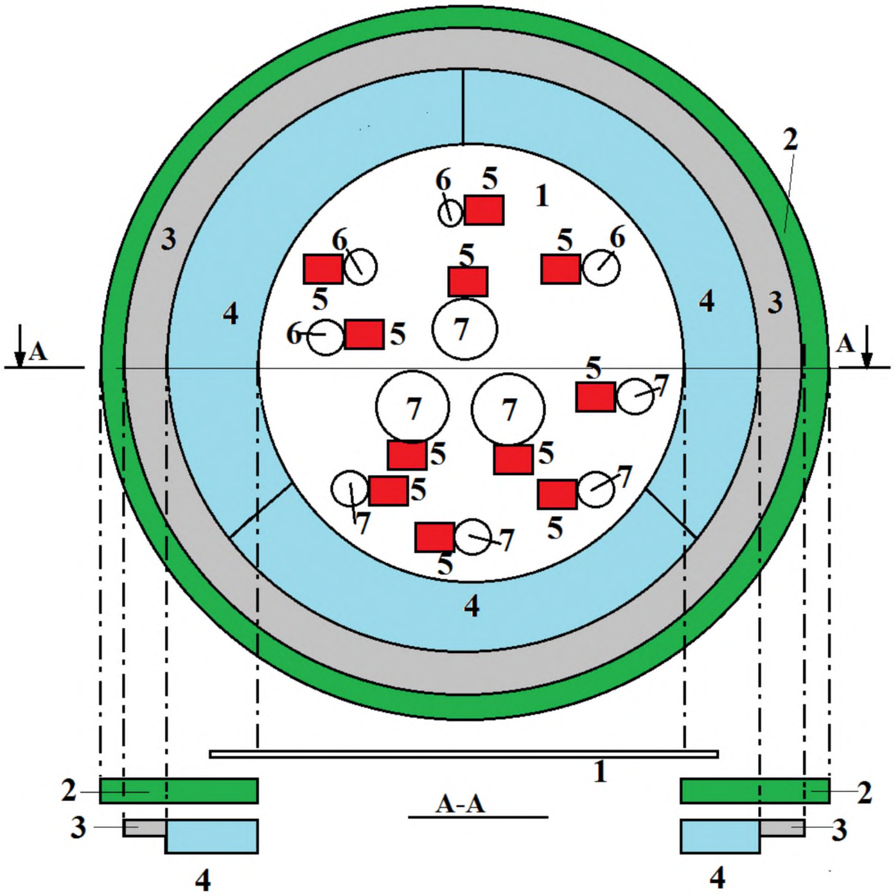


a) non-blast off engine b) recovery engine

1 – LV bottom power belt, 2 – Truss elements of engine suspension,
3 – Engine strong-ring, 4 – Chute boots

Fig 1. Types of engine power connection with LV

A parachute system specially oriented towards LV components recovery is suggested in [7]. The weight of parachute itself should not exceed 160 kg. The refractory fabric and carbon materials for the parachute canopy and shroud lines are widely used in this product. This option provides the arrangement of three similar chute boots, each of which is designed for placement of the main and extraction (stabilizing) parachutes - 4 (see Fig. 2).



1 – Disconnect assembly, 2 – LV bottom power belt, 3 – Engine strong-ring,
4 – Chute boots, 5 –Pyro-cutters, 6 – Cablings,
7 – Pneumatic and hydraulic circuits.

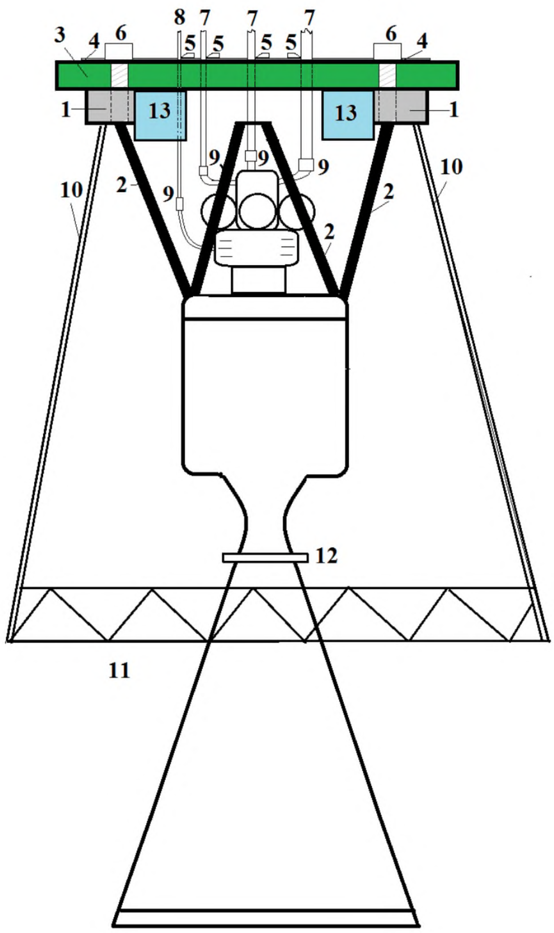
Fig 2. Location of payload disconnect assembly and chute boots.

A disconnect assembly is provided for instantaneous disconnection of cable, pneumatic and hydraulic circuits. This assembly is located in the internal circle of LV power belt (Fig. 2). There are various options for disconnection of cables, pneumatic and hydraulic lines. Separation joints are suggested for the use in some of them (e.g., see [8]). Where there is a high risk of loss of tightness by such joints, it is possible to use pyro-cutters for cutting of cable and tube joints. These devices are located in the disconnect assembly - 1 (Fig. 2). During post-flight maintenance of the engine, the cut cables and lines are to be disconnected - 9 (Fig. 3).

The engine strong-ring and power belt of the LV are fastened by pyro-bolts. Such connection provides longitudinal and lateral stiffness of connection of LV engine and construction within the launching phase of lifecycle. At the same time, this device provides longitudinally free movement at engine separation. The design transversal strength of the pyro-bolts system should be determined based on shearing force occurring during the engine rocks and burns. The value of transverse shearing force may be estimated from the top as thrust vector projection on the strong-ring plane at maximum engine rocking angle. For RD-180 (angle of deviation $\mp 7^0$, sea-level thrust – 390 t/s) this estimation gives 47 t/s considering the reliability factor (1, 3) – 61 t/s.

Engine is mounted on truss absorbers located in the skirt bottom (Fig. 3). The trusses undergo deformation when contacting the truss surface by absorbing the shock energy, and thus reducing overload. Another functional use of the skirt is the provision of engine stability whilst landing. A sufficiently large area of skirt base ensures stall protection.

The above is an estimation of parameters of a recovery system by comparison with the existing parachute systems designed for landing of military hardware. The upper estimate of the weight of the system includes the weight of parachute sections, parachutes, automatic controls and skirt with absorbers, and should not exceed 1500 kg.



1- Engine strong-ring, 2 – Engine suspension trusses, 3 – LV power belt, 4 – Disconnect assembly, 5 – Pyro-cutters, 6 – Pyro-bolts, 7 – Pneumatic and hydraulic circuits, 8 – Cables, 9 – Joints, 10 - Skirt, 11 – Skirt absorber, 12 – Nozzle jet tison, 13 – Chute boots

Fig 3. Engine recovery configuration

Let us estimate the value of impact of the LV mass increase on payload mass due to fitting the recovery system. Launching mass of primary rocket is equal to:

$$m_0 = \sum_{i=1}^{N} (m_i + m_{fi}) + m_{pl}$$

where: m_i dry mass of i-st stage, m_{fi} fuel mass (i-st stage), m_{pl} payload mass.

After modification:

$$m_0' = m_0 + \Delta m_E + m_{pl}' \quad (14)$$

Where Δm_E stage mass gain due to arrangement of recovery system, m_{pl}' new payloadmass.

Efficiency of the LV may be described by the following criterion:

$$\beta_0 = \frac{m_0}{m_{pl}} \quad (15)$$

According to this critereon, [10] can be served as the objective function of approximate optimization of LV original mass. Let us consider the 2-stage LV within-line staging arrangement and oxygen-kerosene engines on both stages. One engine is installed on each stage. Let's insert the parameters according to [10, 11]:

$$x_i = \frac{m_{fi}}{m_{pl}} \quad (16)$$

and stages structural parameters:

$$s_i = \frac{m_i}{m_i - m_{fi}} \quad (17)$$

By inserting the notations:

$$\beta_i = \frac{s_i}{s_i - 1},$$

The condition of optimal selection of masses of stages may be written as follows (see [10]):

$$\beta_0 = 1 + \beta_1 x_1 + \beta_2 x_2 \rightarrow min \quad (18)$$

$$V - \omega_1 ln \frac{1+\beta_1 x_1 + \beta_2 x_2}{1+(\beta_1 - 1)x_1 + \beta_2 x_2} - \omega_2 ln \frac{1+\beta_2 x_2}{1+(\beta_2 - 1)x_2} \leq 0 \quad (19)$$

Where V is the characteristic velocity.

Definition of payload mass of the upgraded product may be made on a direct basis by solving the optimization problem (18-19), where (18) plays the role of the objective function reaching the minimum under condition (19).

The results of the numerical calculation for a payload of 8 ton and an engine with characteristics comparable with RD-180 are given in Table 1 below:

Table 1. Mass characteristics of 2-stage LV

m_0(т.)	m_1(т.)	m_2(т.)	m_{f1}(т.)	m_{f2}(т.)	m_{pl}(т.)	Δm_E (т.)
320	260	60	235	49	8	1,5

Let us define the losses in payload mass associated with the increase in the 1st stage mass due to arrangement of engine recovery system. After upgrading the LV and fitting it with the recovery system, the mass of the 1st stage (with engine) will be increased by $\Delta m_E = 1500$кг. (ratio of engine mass to the mass of the 1st stage is of small value). Variation of objective function:

$$\delta\beta_0 = \beta_1\delta x_1 + x_1\delta\beta_1 + x_2\delta\beta_2 \quad (20)$$

It depends on change in structural parameter S_1, which is subject to vary with the mass growth of the 1st stage engine. The calculation demonstrates the decrease in payload mass by 54 kg.

OUTCOMES

Calculations carried out for the two step carrier (see Table 1) indicate potential for saving the RD-180 engine with the help of a parachute system. The weight increase of the first stage by equipping rescue system is estimated at 1500 kg (max). The compensating loss of payload is 54kg. The cost per kilogram of payload is averaged at $5,000, so the loss of 54kg of payload correlates to a loss of $270,000 per flight. The decrease in the value of the series will be $12 million (USD). This represents about 6% of the value of the series at a cost of $50 million (USD).

Conclusions

Thus, we can see that the salvation of the individual elements of RN possible can lead to increased efficiency in the RN series of launches. At the same time the necessary components and elements individually have long been used in space activities.

Finally, to clarify this issue as possible after a special study that will show the costs of research and development work on the creation of rescue system.

Literature

[1] Shumilin, AA Aerospace US systems. / A.A Shumilin.- M .: Veche, 2005.- 528 p.

[2] Sovetkin, J.A, Sherbina D.V. Offers of "Samara Space Center" to assess the effectiveness of a reusable first stage unit RN [Text] / Yu.A.Sovetkin, D.V.Scherbina // Polet, 2009. no.8.

[3] Gubanov B.I. Triumph and tragedy of "Energy". Reflections of Chief Designer / Gubanov B.I. - t 3: "Energia" - "Buran".. - Lower Novgorod. - NIER.- 1998 [electronic vol.3 [e resource]:. Http://www.buran.ru/htm/gubanov3.htm.

[4] Grishanova AD, Kolychev S.A, Klentak .L.S. Selection criteria for maximizing the quality of the volume level of competitive sales strategies in a duopoly // Vestnik of Samara State Aerospace university.- number 6 (37). - 2012

[5] Tyulevina, E.S Modelling of competitive strategies on the space launch services market in the conditions of globalization: dissertation of candidate of economic sciences: 08.00.13 / Tyulevina Eugene S.; [A protection Place: Sam.gos. aerokosm. Univ . SP Queen] Samara. - 2012. – 22 p. 9 12-4 / 2381.

[6] Grishanova, A.D, Ezhov S.E., Tyulevina E.S. Simulation of the competitive environment in the level of reliability and price of products // Vestnik of Samara State Aerospace university.- number 6 (37). - 2012

[7] YUSHKOV, V.A, Chizhuhin V.N, Mekhonoshin G. Ivanov P.I, / parachute to save the spent rocket stages and other parts of the cargo clearance system in orbit / http: // poleznayamodel.ru/model/11/113240.html.

[8] Erpylev V.V, Rozhkov M.V , Kashintseva V.A Plug the device transit line in the joint fluid of shared parts of a space object and its method of assembly. http://www.findpatent.ru/patent/244/2441822.html // © FindPatent.ru - patent search, 2012-2015.

[9] Dennis R. Moore, Willie J. (Jack) Phelps. Reusable Solid Rocket Motor-Accomplishments, Lessons, and a Culture of Success: AIAA Space 2011 Conference and Exposition Long Beach, CA. - September 27-29. - 2011 / [Net resource]: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120001536.pdf

[10] Kurenkov V.I. Methods of research on the effectiveness of space-rocket systems. Problem-oriented computer-aided design [electronic resource]: electron-throne. Textbooks / VI Kurenkov, A.S.Kucherov; Ministry of Education of Russia, Samar. state. aerokosm. Univ them. SP Korolev (nat. Issled. Univ). - Elektron.tekstovye and graph. Dan. (2.47 MB). - Samara, 2012. - 1 e. wholesale. disk (CD-ROM).

[11] Kurenkov V.I .Selection of the main design characteristics and constructive appearance rockets: Textbooks / B. and Kurenkov, L.P Yumashev. / Ed. corr. RAS D. Kozlov. - Samara: Publishing House of Samar. state. aerokosm. University Press, 2005. - 239 p.

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EXPERIENCE OF BACHELOR'S WORKS ON AIRCRAFT DESIGN IN THE INTERNATIONAL STUDENTS GROUP

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Keywords: education, bachelor's program, aircraft design, international collaboration

Abstract. *The paper considers the system of additional education and preparation of foreign students' bachelor's theses at Samara University. The peculiarity of the system is to carry out research projects within the international group of students.*

1 Introduction

Samara University (Samara State Aerospace University named after S.P. Korolev until 2016) has a long experience with foreign students in the field of preparation work for diplomas, and close collaboration with Beijing Institute of Technology (BIT) in this area has been conducted since 1999. During this time, about 70 students have received training and carried out bachelor's graduate work. The topics and organization of these dissertations have been continuously improved. Execution of group graduate projects in small international teams has been practiced since 2014.

The practice of group diploma design is not new and this method of final training for specialists has been used in the education process at Samara University for a long time. The idea of executing diploma projects in international students' groups has been repeatedly discussed at European Workshop on Aircraft Design Education (EWADE) as one of the most efficient organization forms of training for specialists in Aircraft Design. A student`s team typically includes a chief designer, specialists in aerodynamics, strength, technology and other disciplines. The project group brings the process of task elaboration either to the model, which can be used for aerodynamic tests, or even to manufacturing of a flight sample. The system has many positive features. It motivates the interest during the design activity, provides the skills of work organization, and more. However, such training is not always possible. It requires considerable calendar time to create a group, as well as significantly more time to consult with supervisors.

In the established practice of Samara University and BIT collaboration, the preparation of Bachelor's diploma projects occurs in the spring semester over four months. Under these conditions, the creation of small research groups consisting of several Russian and foreign students is accepted as the main form of diploma theses execution. The last two releases of Bachelor's in Aircraft Engineering have shown outstanding efficiency of the student's group research work. Let us consider some organization features of such work which were developed during the previous cohorts.

2 General Work Plan

2.1 The adaptation period lasts for first two weeks. During this time, the students settle into the University campus. They get acquainted with life organization: the location of the nearest shops, canteen, banks, transport, mobile connection, medical insurance, etc.

On the second day after their arrival, an organization meeting is carried out. The students get acquainted with the supervisors of the chosen topic. Those students from Samara University, who want to work in an international team and have an appropriate level of English, are also invited to the meeting. The meeting outcome is the formation of international creative teams, which work on a specific topic.

During the following days, foreign students get acquainted with the laboratories of the Aircraft Design Department. Classes on clarifying the English terms that are used in aviation technology and the system of acronyms accepted in international practice are held. Teachers spend an interview on the basics of aerodynamics (physical and virtual simulation experiment), on the basics of structural mechanics and finite-element method in order to identify the need for additional training and recruitment of additional literature on these subjects. Every day, students have practical classes and consulting on Russian language.

2.2 Preparation of Diploma Project

2.2.1 Topics of graduate projects

Selection of topics is one of the key issues, and one which should ensure a high learning effect from the final qualifying work. The topic should encourage students' self-educational activity in a particular direction. It should be conversant with the advanced achievements of the University in this area. In addition, the set of topics should be sufficiently varied to prepare highly qualified specialists in the different areas of Aeronautic sciences: aerodynamics, structural strength, conceptual design, composite materials and structures. Topics of graduate projects are developed and coordinated with the University-partner in advance. The depth of elaboration within the topic is confirmed during the work implementation phase.

For instance, following are the topics of BIT students' research projects, from Samara University in 2015 and 2016:

1) Design of Training Aircraft
2) Design of an Aircraft for Local Airlines
3) Aerodynamic Characteristics of Variable Aspect Ratio Wings
4) Structural Design of High-Loaded Parts
5) Calculations of Aerodynamic Loads on Aircraft Wing Spoiler
6) Calculation of Aerodynamic Characteristics of Transport Aircraft

7) Optimization of Wings for Passenger Aircraft
8) Mathematical modeling of stress-strain state of wing panel made of composite materials during its production process
9) Designing of strong aircraft frames
10) Aircraft with great flight duration
11) Cargo and passenger aircraft for regional transportation
12) Development of equipment for testing curved beam and tube structural elements made from composite materials
13) Experimental study of aerodynamic characteristics of a wing with a spoiler
14) Mathematical modeling of wing aerodynamics taking into account its deformations
15) Research of the ground effect influence on the aerodynamic characteristics of a wing with low aspect ratio

2.2.2 Organization of work performance

The Aircraft Design Department has a special classroom, which is available from 8.00 to 20.00 to ensure comfortable operation of the international groups. There are Internet access, multimedia tools and the possibility of coffee breaks. In this classroom, supervisors consult students at least twice a week. All project participants can take part in the consultations. The practice of the last two years has shown that it is effective to involve undergraduates.

Implementation of research work is conducted strictly according to the schedule and often with an over-fulfillment of the amount of planned research. For instance, student ZANG Yue who carried out a project about the designing of a strong aircraft frame expressed the wish to additionally explore the problems of using composite materials in aeronautic engineering.

In mid-April (the first half of term), all students usually make a detailed presentation about the work done thus far. This allows control of the projects performance according to the schedule. Discussions clarifying tasks and the scope of works are held during these presentations.

At the end of student's stay at Samara University, a pre-defense of the final graduate projects is held. As the result, an evaluation of the presented project will be conducted and the supervisor will write a review about students' work throughout the internship.

The official defense is carried out at the students' home universities.

Figure 1: BIT graduates after defense

2.2.3 Material base

The Aircraft Design Department of Samara University has a unique material base. It includes the laboratory of aircraft structures where an extensive collection of aircraft and units of various countries and epochs is presented (more than 100 exhibits). The exhibits allow to see in practice the basic designing and technological solutions used in aircraft design.

Figure2: Classes in the Aircraft Structures Lab

During the internship, students attend the aerodynamic laboratory where they perform a number of practical tasks using an aerodynamic tube.

An operating model of a Tu-154 is presented in the aircraft equipment laboratory. Here students are acquainted with the electrical and radio equipment of the aircraft and its main onboard systems.

In the composite materials and structures laboratory, students study manufacturing technologies, existing standards, and testing processes of composite materials. Students have an opportunity to make composite samples using vacuum infusion technology and carry out their testing.

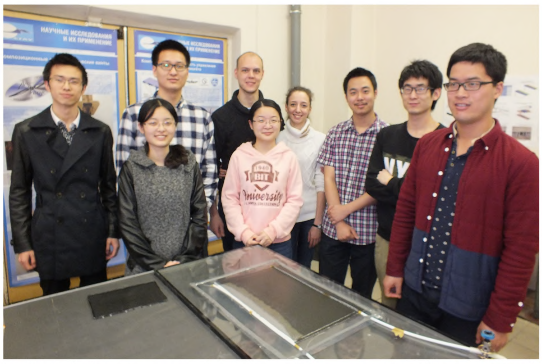

Figure4: Making samples in Composite Materials Lab

2.2.4 The methodological and information support

All research topics are provided with English-language scientific and technical literature in the form of original books and Internet links to the necessary literature.

The training manual "Aircraft Conceptual Design" was prepared in English especially for foreign students. It reflects the long experience of teaching this discipline in Samara University. It also allows students to gain insight about all kinds of design work, from the selection of aircraft shape, up to calculation of its weight characteristics within a reasonable time. The work ends with the drawing of the general view of the aircraft and its main technical characteristics.

Students have access to the electronic recourses of Samara University Library and have an opportunity to work with a wide range of licensed software: STAR-CD, NASTRAN, ANSYS, AAA (Advanced Aircraft Analysis), CATIA, Creo-Element, etc.

2.2.5 Student's timeframes

Training classes:

		Hours
1	Introduction to aviation science and technology	6
2	Basics of aerodynamics	12
3	Basics of aircraft construction	12
4	Computing system NASTRAN	12
5	Computing system ANSYS	12
6	Computing system STAR-CCM+	8
7	Acquaintance with laboratory of aircraft structures	4
8	Acquaintance with aerodynamics laboratory	4
9	Acquaintance with aircraft equipment laboratory	4
10	Acquaintance with composite materials and structures laboratory	4
11	Individual work with literature	66
	Total:	144

Implementation of qualifying work is 456 hours, including 50 hours of consultations with the supervisors.

3 The language selection for business communication

In our opinion, it is appropriate to use English as the business language in the international teams on engineering in the present conditions. However, there are no strict requirements on the level of language knowledge.

Our experience shows that both the Chinese and Russian students have certain language difficulties at the beginning. The student's daily communication in English allows the language barrier to be overcome very quickly, and students begin to communicate more confidently, they clearly formulate their thoughts and progress together in the use of English.

We consider this to be an important effect of working in the international group.

4 Cultural program

The cultural program, which involves the entire international group, promotes a rapid adaptation and development of communication skills. Samara University students give a city-tour for BIT students with a visit to popular Samara sights. Among others, the group visits the beautiful Volga River embankment stretching over 5 km. A cruise along the Volga by ship shows the students the most beautiful places of the Samara region.

The cultural program usually includes a visit to the Philharmonic Hall, the Opera and the Ballet Theatre. All this allows foreign students to get acquainted with Russian culture and traditions. The visit to the aviation and space technology museum, as well as the unique museum of aircraft engines can be referred to in the cultural program. During the May holidays, Chinese students usually go to St. Petersburg and Moscow.

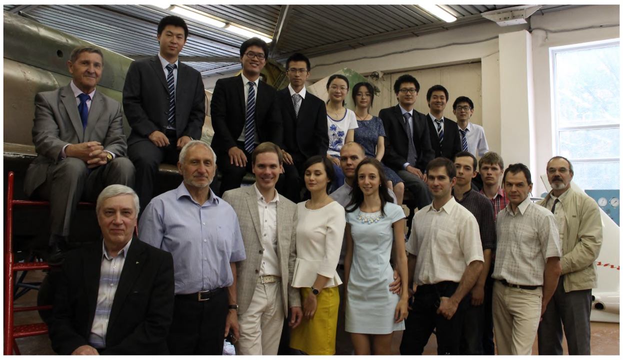

Figure 6: International team and supervisors

Conclusion

Samara University's well-developed system for the preparation of Bachelor’s qualifying projects in international teams has shown great advantages compared with the traditional system of individual graduate work:

1. The transition period when students adapt to the life and conditions of a foreign culture, education system and language, becomes shorter and easier.
2. The research activity involving all of the partnership participants, motivates and activates both supervisors and students.
3. The joint work of a large team promotes the expansion of future specialists’ technical and cultural outlook.
4. Youth exchange contributes to the establishment of friendly relations between students and universities of different countries.

DESIGN-BUILD-FLY PROJECTS OF LIGHTER-THAN-AIR SYSTEMS FOR ENHANCED LEARNING OF AIRCRAFT DESIGN PRINCIPLES

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Key words: LTA Systems, Airships, Aerostats, Design-Build-Fly projects

Abstract. *This paper shares the experiences of teaching the principles of aircraft design to a group of undergraduate students by assigning "design-build-fly" (DBF) type projects related to Lighter-Than-Air (LTA) systems. In a classical aircraft design course, students are generally made to carry out a paper design of an aircraft that meets some user-specified and regulatory requirements. In some cases, such projects are of DBF type, and mostly related to Gliders, Quadcopters, or UAVs. While this approach has its own merits, one of the key limitations is that success in accomplishing such tasks requires good piloting and/or aeromodelling skills. It's quite common for student teams to spend many hours in fabricating an aircraft that they have designed, and only a few minutes in breaking it beyond any repair! LTA systems, on the other hand, are quite forgiving and robust, and often pose far greater challenges in sizing, fabrication, system integration and flight testing compared to their heavier-than-air counterparts. This paper provides many examples of such projects successfully completed by student teams, and presents a case for including LTA systems based DBF project to undergraduate students of aerospace engineering.*

1 INTRODUCTION

The subject of Aircraft Design is part of the core curriculum in most universities around the world, which run an undergraduate (UG) degree specialization in Aeronautical and/or Aerospace Engineering. Many of these universities teach this subject in a "hands-on" mode, either partially, or fully. In some universities (e.g., at NTU Singapore), the students are divided into teams, and each team is given the task of carrying out a conceptual design of an aircraft meeting some specified requirements, on paper (or, more appropriately, a computer), over a semester. The faculty member(s) that conduct this course try to impart the "design knowledge" via some lectures, instructions and reviews of the design that the various teams work out.

In some other universities (e.g., Virginia Tech in USA), the course is spread over two semesters. In the first semester, primarily, some theoretical and procedural inputs in carrying out a conceptual design are imparted. During the second semester, the student teams are given a choice; some go for *design-build-fly*(DBF) projects (mostly as part of some competition, e.g., the AIAA Design Build Fly competition), whereas some others take up computer-based designs of aircraft that are not amenable to the DBF mode in a university environment, due to constraints on the facilities and equipment available, and the costs.

The author has been involved in teaching this subject for over two decades at the Aerospace Engineering Department of IIT Bombay. Over the years, the manner in which this subject is taught has undergone many changes, some to keep in line with the developments in this field, but mostly also due to the constraints of non-availability of faculty members with suitable background and training to handle such a course. In the current avatar, the UG students in the sixth semester of an eight semester program, undergo a taught course, in which the history, background, principles, procedures, and special considerations in conceptual design of an aircraft are imparted, using some examples and case studies. However, engineering design is best learnt by doing it, and one needs to get their hands dirty to appreciate and develop a designer's mind-set, for which the DBF projects come in very handy. Hence, an Aircraft Design laboratory course is also conducted in the seventh semester. In this, the student cohort is divided into groups and made to carry out hands-on design projects which aim to create a physical system meeting certain requirements and expectations. As mentioned above, some teams may decide to undertake theoretical computer-based design projects, especially if they want to address some contemporary challenges in Aerospace Engineering or take part in some competitions, e.g., AIAA Student Individual or Team Design Competitions.

Most of the DBF projects taken up by student teams tend to be related to Gliders or Remotely Controlled UAVs, the most popular one being Quad- or Multi-copters. One of the problems that many students encounter when they attempt such DBF projects is lack of past experience in making things by hand. Part of the blame for this goes to the current UG engineering education system, in which we are slowly moving away from imparting practical skills, and focusing more on computer based skills. On the other hand, society in general is also moving towards more computer (and now hand-phone) based activities, so the students are naturally more familiar with these systems, rather than the machines used for fabrication, e.g., lathe and drilling.

The other problem that novices face is that most aerospace systems are inherently unstable and complex, and it is not easy to make them crashworthy and robust. Moreover, many students do not have the necessary piloting skills and experience in safely operating an aerospace vehicle, and expecting most students to acquire these skills before they attempt an aircraft design exercise is a tall order. In such a scenario, it is a very common occurrence that a student team takes, say, five days to fabricate a remotely controlled aircraft or quadrotor, but just five minutes to break it beyond repair! This leads to a sense of frustration and, in several cases, demotivates the student cohort enough not to attempt any further work. Further, the design and fabrication of systems like Quadrotors is mostly driven by Avionics and Control, and there may be little or no scope for exploring the knowledge gained in subjects like Aerodynamics (and to some extent Structures) in fabricating such systems.

This paper shares the experience of the author in teaching design principles and thinking to teams of UG students, by taking up DBF projects in the field of Lighter-Than-Air (LTA) systems. The next section provides a brief overview and history of LTA systems, and some recent developments. Some DBF projects that have been successfully carried out by UG students and interns are illustrated. Finally, the key challenges and benefits of carrying out DBF projects in LTA systems are highlighted, and a justification for taking this approach is provided.

2 LIGHTER-THAN-AIR SYSTEMS

Lighter-than-Air (LTA) systems are aeronautical systems that derive most of their lifting force to overcome gravity by the principle of buoyancy. This is in direct contrast to Heavier than Air (HTA) aeronautical systems, which use motion relative to the ambient air for generating the aerodynamic forces to overcome gravity. The predominant lift-generating component of an HTA system is its wing or rotors, while that of an LTA system is an envelope filled with an LTA gas, e.g., Helium or Hydrogen. The difference in weight of the air displaced by the envelope and the LTA gas filled within results in buoyant force. The Net Lift L_{net} of an LTA system can be calculated using Eqn. 1:

$$L_{net} = V_{env}(\rho_a - \rho_g) \tag{1}$$

Where V_{env}= envelope volume,and ρ_a, $\rho_g$are densities of ambient air & LTA gas, respectively.

LTA systems can be broadly classified into three main categories, viz., Balloons, Airships and Aerostats. Balloons normally uses hot air or LTA gas to generate lift, and are mostly spherical or teardrop in shape, with no propulsive system. Airships consist of an aerodynamically shaped envelope and are fitted with a propulsive device for providing forward motion, and a flight control system to provide directional stability and control. Aerostats, on the other hand, are designed to remain stationary; they consist of an aerodynamically shaped envelope tethered to the ground. Adequately sized fins are mounted on the envelope to allow the envelope to weathercock and provide stability. Fig. 1 showcases the three principle types of conventional LTA systems.

Balloon Aerostat Airship

Fig. 1: Three types of conventional Lighter-Than-Air systems

2.1 History of LTA systems

The history of LTA systems dates back to 220-280 AD when the Kongming lantern became popular in China. These lanterns used the principle of hot air ballooning for generating lift forces and remained afloat, illuminating the sky. In 18th century AD, Joseph and Etienne Montgolfier conducted a series of experiments with hot air balloons and succeeded in the first manned flight in 1783. Around the same time, Jacques Charles and the Robert brothers made the first manned flight using a hydrogen filled balloon. Numerous experiments were subsequently conducted for adding power to hot air and gas balloons which evolved into aerodynamically shaped airships. Balloons have limited applicability for scientific and commercial applications, since they are totally at the mercy of the ambient wind. Current uses of balloons are limited to collection of weather related data or hot air ballooning as an adventure sport. The two LTA systems that are most popular and capable of commercial or scientific exploitation are Aerostats and Airships, and their historical developments are described in the two sub-sections that follow.

2.1.1 Aerostats

The history of Aerostats in military warfare dates back more than two and half centuries. Observation balloons and aerostats have been used in battle since the 1790s; their first reported use was during the French revolution. US military forces have used a network of Tethered Aerostat Radar Systems (TARS) since December 1980, first to help counter illegal drug trafficking, then for border protection by keeping a check on illegal immigration, and later for low-level surveillance coverage for air sovereignty. TARS have also been used very effectively to support the US military in its operations in Afghanistan in 2001 and Iraq in 2003.

2.1.2 Airships

The "Golden Age of Airships" began in 1900 with the launch of *Zeppelin* which was named after Count Ferdinand von Zeppelin. Zeppelin Airships were the most successful airships of all time and were extensively used for air transportation, as well as bombers during World War I. The United States and Britain also built several Airships during 1920s and 1930s, for example, *R-33* and *USS Shenandoah (ZR-1)* respectively, although these mostly imitated the original design of the Zeppelin. During the 1930s, airships were the luxury liners of the sky, ferrying passengers across the Atlantic in comfort and style, a far cry from the cramped conditions that the vast majority of air travelers today are forced to put up with. Today, however, in the minds of the general public, the very word 'airship' today conjures up a vision of a bygone era, and airships suffer from a connotation of being dangerous and unsafe. This is mainly due to a series of fatal accidents between 1910 and 1940, which lead to their downfall. The most noteworthy accidents were the crash of the British airship *R101* in France and burning of the *Hindenburg*, the largest airship ever built, leading to the loss of crew and passengers. After World War II, Airships were deemed to be obsolete due to advancements in HTA aircraft technology, and were sent into a quiet oblivion.

3 PRESENT DAY LTA SYSTEMS

Today, Aerostats are the aerial platform of choice for long duration surveillance applications, when the ambient weather conditions are mostly calm or not very disturbed. Due to the aerodynamically efficient shape of the envelope, as well as provision of adequately sized fins, an aerostat can be designed to remain fairly steady even in strong ambient wind conditions. Depending on the payload, range of surveillance, and operational time, these aerostats can be launched to any desired altitude from a few meters above ground level, to as high as 5000 m above ground level. Of course, the payload-carrying capacity of an aerostat is reduced as its operational height is increased. Aerostats can be easily and quickly deployed at high altitudes, ensuring a long-endurance, and stable surveillance system, with much lower distortion levels. Once they are deployed, there is very little recurring additional expenditure to keep them afloat, mostly in the form of small amounts of LTA gas, just to top-up for the leakages through the fabric over a period of time.

Over the years, technological developments in aerospace engineering have made airships much safer, chiefly due to the availability of Helium as an inert LTA gas, and much superior material and control systems. Many researchers today believe that airships present an effective, low-cost, environment friendly solution for some niche areas of air transportation, such as hauling cargo over remote locations such as Canada and Alaska. This has spawned many studies and technology development initiatives worldwide, and it can be said that airships are now undergoing a revival. Airships can be very effectively used in regions where economic considerations are a key driver towards solving the transportation problems, especially in providing air transport service to remote communities. The costs related to setting up and operating the infrastructure required for operating airships are quite small, compared to that for their heavier-than-air counterparts. Further, the operating costs of airships can also be quite low, primarily due to their low fuel consumption.

In recent times, there has been a significant interest to revisit LTA systems, mostly due to their cost effective and environmentally-friendly deployment for scientific, civil and military applications [1]. With the advancement of technologies like composite materials, durable fabrics and techniques of research, and developments like finite element analysis (FEA) for structural analysis, Computational Fluid Dynamics (CFD), Fluid Structure Interaction (FSI), design optimization, thermal modeling and automated control, modern Airships and Aerostats are getting much more refined and safe and hence, are facing a major revival. They are being proposed for a wide range of applications such as advertising and tourism, surveillance, environmental monitoring, planetary exploration, heavy-lift cargo transport and telecommunication relays.

IMPORTANCE OF *DBF* PROJECTS

Many institutions all over the world are attempting to incorporate CDIO (Conceive-Design- Implement-Operate) strategy in their UG education systems. In 2001, MIT in the USA took the lead in implementing a CDIO strategy in their UG aerospace engineering curriculum, by arriving at a statement of goals for engineering education. This strategy was updated a decade later in 2011 [2]. DBF projects are an integral component of a CDIO based education strategy in any aeronautical department, and their successful implementation in the

MIT curriculum has been explained by Young et al. [3].

There is a general misconception that implementing a CDIO strategy in UG teaching needs huge amount of resources, and results in much higher operating expenses. In 2003, MIT and three leading universities in Sweden developed a survey that allows an engineering school to benchmark curricula for teaching personal, interpersonal and system building skills, all of which are enumerated in a CDIO syllabus, and all of which are required in a well-rounded aerospace engineer. The results of this survey indicated that no additional resources are needed in following a CDIO approach in UG teaching; it is enough to simply follow a consistent and deliberately designed syllabus [4].

MIT was also the first institution to implement Lighter-Than-Air systems-based DBF projects as part of their curriculum in the freshman year. This exercise has been described in detail by Newman [5], in which she mentions that the lighter-than-air vehicle design competition provides an opportunity to apply the fundamental concepts and approaches of aerospace engineering in the context of the design. This opinion is totally supported by the experience of this author, as described in the next section.

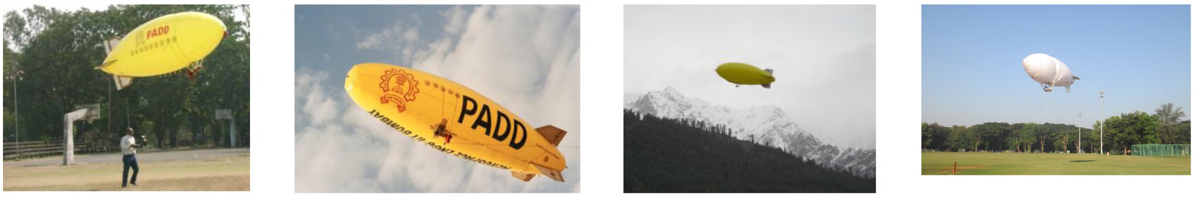
4 *DBF* PROJECTS ON LTA SYSTEMS AT IIT BOMBAY

In 2001, the Program for Airship Design and Development (PADD) was launched at IIT Bombay, with team members drawn from various national aerospace organizations and private sector companies in India. One of the objectives of PADD was to get updated with the global developments in Lighter-Than-Air (LTA) technology. In the first phase of PADD, techno-economic feasibility of leasing airships for transportation of goods and passengers over mountainous terrain under 'hot and high' conditions in India was investigated. As an offshoot of the PADD program, a Lighter-Than-Air Systems Laboratory was set up in IIT Bombay in 2004.

One of the key outcomes of PADD was the development of a methodology for the design of a non-rigid airship. By using this methodology, one can arrive at the baseline specifications of a non-rigid airship that meets user-specified requirements [6]. The methodology estimates the envelope volume required to carry a user-specified payload and also arrives at the mass breakdown and performance estimates of the various components. Alternatively the payload that can be carried by an airship of specified envelope volume can also be estimated.

4.1 Outdoor Remotely Controlled Airships

The first DBF project to be implemented in LTA laboratory was an outdoor remotely controlled non-rigid airship in 2002, named *MICRO* [7], in which the abovementioned methodology was modified for carrying out sizing and baseline design calculations of a remotely controlled airship. The design requirements specified for *MICRO* were very modest; it was required to have a payload capacity of 1.0 kg, while operating at a maximum speed of 30 kmph for 20 minutes, using an existing IC engine developing 0.41 BHP. Due to constraints on storage space, it was required to be less than 5.00 m in length. An extended version of the *MICRO*, named *MINI*, was developed in 2003, with an increased payload capacity of 3.0 kg [8]. In 2009, an outdoor airship named *MACRO* was developed for snow cover evaluation of lower Himalayas [9]. Recently, a remotely controlled airship named *AUTON* has been developed and flight tested. This airship was meant to act as a test platform for an outdoor autonomous airship [10]. Fig. 2 shows the photographs of these four airships. Their key parameters are listed in Table 1.



MICRO[7] *MINI* [8] *MACRO* [9] *AUTON*[10]

Fig. 2: Outdoor airships designed and developed at LTA Systems Laboratory of IIT Bombay

Year of development → **Parameter ↓**	***2002*** ***MICRO***	***2003*** ***MINI***	***2009*** ***MACRO***	***2013*** ***AUTON***
Length (m)	4.99	6.42	8.00	8.00
Envelope Volume (m^3)	6.8	8.6	26.6	24.7
Payload (kg)	1.0	3.0	6.0	15.8
Endurance (min)	15	18	25	30
Max. Speed (m/s)	7	10	12	15
Engine Power (HP)	0.41	0.60	2.0	T = 6 kg

Table 1: Key parameters of outdoor airships

4.2 Indoor Remotely Controlled Airships

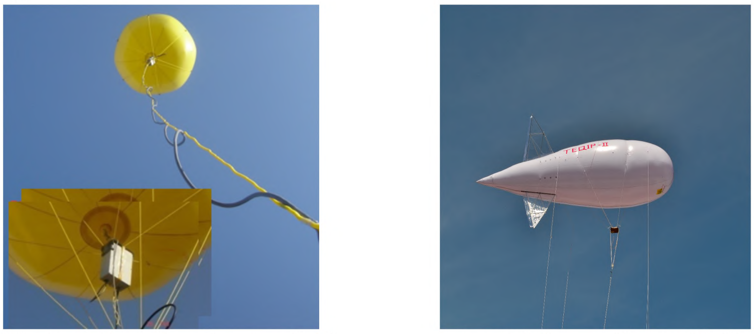
Since 2004, several indoor airships have also been developed by students as part of DBF projects. The envelope profile of these airships vary from Oblate Spheroid, Zhiyuan, and NPL. A biomimetic airship was also developed, which mimics the motion of a Rainbow Trout fish. The photographs of four such airships are shown in Fig. 3.

OSIRCA [11] *Black Beauty*[12] *NPL* [13] *Biomimetic*[14]

Fig. 3: Indoor airships designed and developed at LTA Systems Laboratory of IIT Bombay

4.3 Tethered Aerostat Systems

Two tethered aerostat systems have also been developed as DBF projects. The first project was to demonstrate aerostats as a relocatable aerial platform for providing communications in remote areas during emergencies. Two field trials were conducted in 2007, in which the efficacy of the system was established for wireless data and voice communications over a radius of ~ 10 km [15]. In 2014, a tethered aerostat system for aerial surveillance in a college campus was also developed and successfully field tested [16]. Fig. 4 shows photographs of these two systems.



Wireless Communication[15] Aerial Surveillance [16]

Fig. 4: Two tethered aerostat systems developed under DBF projects

5 CHALLENGES AND BENEFITS OF LTA *DBF* PROJECTS

DBF projects in LTA systems offer several interesting design challenges in terms of weight management, envelope fabrication techniques, and the need for ground support systems. These projects also impose many constraints, for example, the cost and availability of LTA gas, and the larger space needed to operate the system and then store it when not in use. One major constraint, especially in outdoor LTA systems, is the issue of operational safety in case of system failure; if the system goes out of control, it could possibly drift into controlled airspace and cause interference with commercial or general air traffic! LTA systems are very robust and do not easily get damaged when mishandled. Since airships operate at low speed and are bulky, they respond slowly to control inputs, so students can quickly learn to fly them. Aerostats completely remove the need for piloting skills, although they need a winching and mooring system to operate them.

During the last decade and a half, the supervising teams of UG students for several DBF projects reported that none of the systems were lost, or suffered any catastrophic failure during deployment or testing. While carrying out these projects, students have experimented and solved several design and operational problems, which has made their experience quite enriching. It has also encouraged them to think of novel approaches and learn to tackle new problems. Once such example is the design and field testing of an on-board mounted device for safe recovery of payload in case an aerostat tether is accidentally severed during deployment [17-18], design and fabrication of mooring masts for indoor and outdoor airships [19] and field deployable winch for aerostat are examples of fall-out projects [20].

6 CONCLUSIONS

Based on the experience of over two decades of teaching aerospace design to UG students, and the reasons mentioned above, it is recommended that DBF projects related to LTA systems should be included in the syllabus, because they can go a long way in providing an excellent learning experience, and can inject new ideas into the minds of budding engineers.

REFERENCES

[1] C. Bolkcom, "Potential Military Use of Airships and Aerostats", Report ADA467685, Congressional Research Service, The Library of Congress, 2004.

[2] E. F. Crawley, J. Malmqvist, W. A. Lucas and D. R. Brodeur, "The CDIO Syllabus v2.0, An Updated Statement of Goals for Engineering Education", Proceedings of the 7th International CDIO Conference, Technical University of Denmark, Copenhagen, Denmark, 2011.

[3] P. W. Young, O. L. De Weck and C. P. Coleman, "Design and implementation of an Aeronautical Design Build Fly course", Proceedings of the American Society for Engineering Education Annual Conference & Exposition, Washington DC, USA, 2003.

[4] J. Bankel, E. F., K-F. Berggren, M. Engstrom, I., Wiklund, E. F. Crawley, D. Soderholm, K., El Gaidi, and S. Ostlund, "Benchmarking Engineering Curricula with the CDIO Syllabus", International Journal of Engineering Education, Vo. 21, No. 1, pp. 121-133, 2005.

[5] D. Newman, "Interactive Aerospace Engineering and Design", Boston, McGraw Hill, 2002.

[6] R. S. Pant, "A methodology for arriving at the baseline specifications of a non-rigid airship", AIAA Journal of Aircraft, Vol. 45, No. 6, pp. 2177-2182, 2008.

[7] A. C. Gawale and Pant, R. S., "Design, Fabrication and Flight Testing of Remotely Controlled Airship", National Conference on LTA Technologies, ADRDE, Agra, India, 2002.

[8] A. C. Gawale, A. A, Raina, R. S. Pant & Y. P. Jahagirdar, "Design Fabrication and Operation of Low Cost Remotely Controlled Airship", AIAA-2008-8853, Proceedings of 26th Congress of ICAS &8th AIAA ATIO, Anchorage, Alaska, USA, 2008.

[9] R. S. Pant, "Design, Fabrication and Flight Demonstration of a Remotely Controlled Airship for Snow Scientists", Journal of Aerospace Technology and Management (JATM), Vol. 6, No. 1, pp. 19-27, doi: 10.5028/jatm.v6i1.313, São José dos Campos, Brazil, 2014.

[10] I. A. Khan, N. I. Motiwala, S. Mulay, V. Sharma, and R. S. Pant, "Design, Fabrication and Testing of Outdoor Autonomous Airship", AIAA-2013-1296, Proceedings of 20th AIAA LTA Systems Technology Conference, Daytona Beach, FL, USA, 2013.

[11] K. Kanagaraj, K. Kamalraj, A. Saravanan, G. Krishnan, B. Devarajan, and R. S. Pant, "Design-Build-Fly of OSIRCA: Oblate Spheroid Indoor Remotely Controlled Airship",

AIAA-2011-6914, Proceedings of 19th Lighter-Than-Air (LTA) Technology Conference, Virginia Beach, Norfolk, Virginia, USA, 2011.

[12] N. I. Motiwala, N. P. Yelve, I. A. Khan, B.E. Narkhede and R. S. Pant, “Conceptual Approach for Design, Fabrication and Testing of Indoor Remotely Controlled Airships”, Proceedings of 4th International Conference on Manufacturing Science and Engineering, Dalian, China, Advanced Materials Research, Vols. 690-693, pp. 3390-3395,2013.

[13] G. Bansal, U. Bhardwaj, N. Jain, S. Mulay, S. Sawardekar, and R. S. Pant, “Design Fabrication and Flight testing of a Non-rigid Indoor Airship”, Paper AIAA-2013-1297, Proceedings of 20th AIAA LTA Systems Technology Conference, Daytona Beach, FL, USA, 2013.

[14] A. Udaykumar and R. S. Pant, “Design and Fabrication of Biomimetic Airship”, Proceedings of National Level Conference on Advances in Aerial/Road Vehicle and its Application, MIT, Manipal, India, 2014.

[15] A. Raina, P. Bilaye, V. N. Gawande, R. S. Pant and U. B. Desai, “Design and Fabrication of an Aerostat for Wireless Communication in Remote Areas”, AIAA-2007-7832, Proceedings of AIAA 17th Lighter-Than-Air Systems Technology Conference, Belfast, Northern Ireland, UK, 2007.

[16] N. Sharma, R. Sehgal, R. Sehgal, and R. S. Pant, “Design Fabrication and Deployment of a Tethered Aerostat System for Aerial Surveillance”, Proceedings of National Level Conference on Advances in Aerial/Road Vehicle and its Application, MIT Manipal, India, 2014.

[17] C. Bhat and R. S. Pant, "Design of a Payload Recovery Device in case of accidental breakage of tether of an aerostat", AIAA-2011-7022, Proceedings of 19th Lighter-Than-Air (LTA) Technology Conference, Virginia Beach, Norfolk, Virginia, USA, 2011.

[18] N. Sharma, A. Mukhopadhyay, V. Sharma, M. Milind, and R. S. Pant, "Design and Field Trials of a Payload Recovery Device for Tethered Aerostats", In R. P. Bajpai, U. Chandrasekhar & A. R. Arankalle,(eds.), Lecture Notes in Mechanical Engineering, pp. 79-84, DOI: 10.1007/978-81-322-1871-5_12, ISBN 978-81-322-1871-5, Springer India, 2014.

[19] U. Bhardwaj, K. Syed and R. S. Pant, “Design, Fabrication and Testing of Mooring Masts for Remotely Controlled Indoor and Outdoor Airships”, Journal of the Institution of Engineers (India): Series C, Mechanical, Production, Aerospace and Marine Engineering, Springer, ISSN: 2250-0545, Volume 97, Issue 2, pp. 257-277, 2016.

[20] K. Bhandari, N. Wanjari, S. Kadam, G. Sequeira and R. S. Pant, "Design, Fabrication and Field testing of Winch for Aerostat", Proceedings of National Seminar on Strategic Applications of Lighter-Than-Air (LTA) vehicles at High Altitudes (SALTA-07), SASE, Manali, India, 2007

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TRANSPORT EFFICIENCY OF AIRCRAFT WITH AIR-CUSHION LANDING GEAR

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Key words: Air-cushion, Transportation, General Aviation

Abstract. *This article gives general information about aircraft with Air-Cushion Landing Gear (ACLG). The ACLG concept exhibits significant and considerable advantages when comparing the Dingo experimental aircraft, fitted with ACLG, with other types of aircraft. Finally, the article provides a potential plan for air traffic networks using ACLG-equipped aircraft.*

1 INTRODUCTION

Nowadays, there is an important state concern in many countries, and that is to be able to provide a reliable and economical civil air transport service, both for private enterprise and individuals, as well as for federal agencies and services. This is particularly true in regions with poorly-developed airdrome networks or transport systems, as the costs to develop regular airfields, their infrastructure and their maintenance, are extremely high. One of the more promising ways to partly or entirely solve these problems is the development of aircraft with Air-Cushion Landing Gear (ACLG).

Some of the advantages of aircraft fitted with ACLG, relative to other types of aircraft:

1.Capability to take-off and land on different surfaces (ground, snow, water, mixed surfaces, etc.) regardless of surface firmness, and exceed acceptable ratings for rough landings on conventional wheeled landing gear by up to 5-10 times;

2.Capability to land on waters of uncertain depths, irrespective of submerged objects, and come ashore without a concrete slipway;

3. High operational capability to perform regular and various transport tasks with minimal dependence on weather conditions and aerodrome supply level.

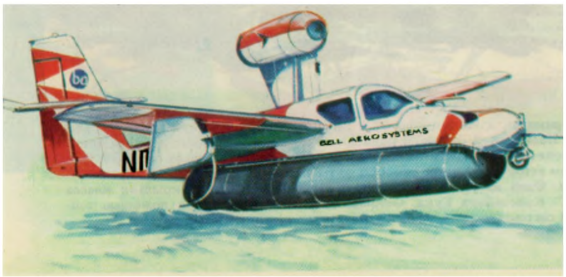
However, the ACLG disadvantages are:

1. Structural complexity;
2. Significant effect on aerodynamics;
3. Higher cost-value compared to wheel landing gear;
4. High maintenance costs.

We need to determine if the development of ACLG can lead to significant costs improvements in regions with poorly developed airdrome infrastructure and whether its support makes economic sense or not. The world's first experimental aircraft designed with ACLG, the UT-2, was designed in the USSR in 1940 by N.I. Nadiradze and A.D. Efremov (Fig.1).

Figure 1: UT-2 with ACLG

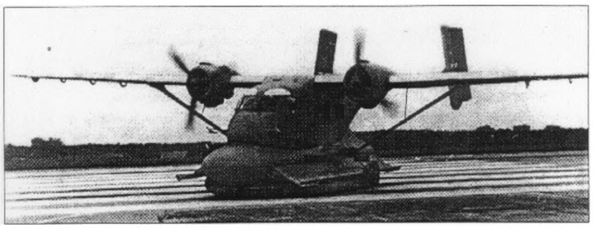
Since this first design, there have been around 20 aircraft designed with ACLG, some of which are shown in Fig.2. The principle and efficiency of ACLG were tested on conventional wheeled or amphibian aircraft, modified by fitting different air-cushion designs.



a) Amphibious aircraft Lake-4 with ACLG (Canada, USA, 1974)

b) Aircraft with ACLG DHC-5/CC-115«Buffalo» (Bell Aerospace 1971/USAF 1975-79 Canada, USA)

c) Aircraft with ACLG An-714 (Russia, 1970)



d) Aircraft with ACLG An-14Sh (USSR, 1983)

e) A.I. Filimonov Aircraft with ACLG (Russia, 1993)

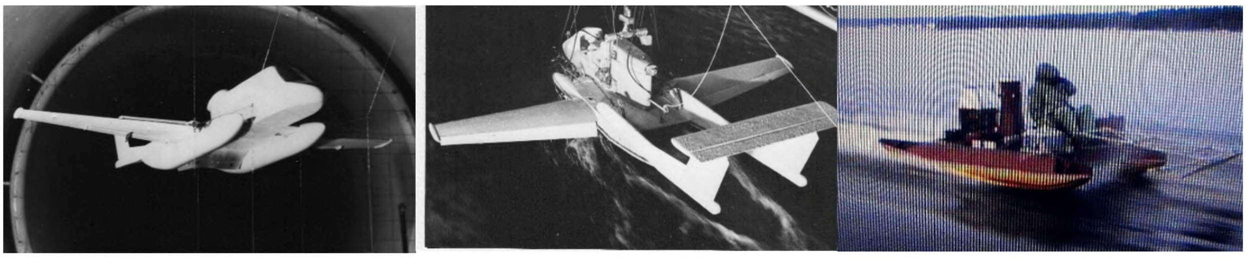
f) O.A. Cheremukhin Light aircraft with ACLG (Russia, 2000)

Figure 2: The most known models of aircraft with ACLG

2 'DINGO' EXPERIMENTAL PLANE

In the USSR during the late 1980's, a conceptual stage of ACLG: the "early alignment principle" of air-cushion landing gear with a basic aerodynamic arrangement, was proposed in order to decrease the negative impact on aerodynamics, as well as procedure and approach. For aircraft with ACLG, developments were designed considering features of the air-cushion and its effect on aircraft performance. The mentioned principle allowed cutting weight and substantial aerodynamic loss, and retaining the high operational performance of the aircraft in the project. The principles and design procedures of amphibious aircraft were tested on the Dingo experimental aircraft with ACLG and a range of aircraft and ekranoplanes (ground effect vehicles: GEVs).

Dingo experimental aircraft were developed under the direction of the author and designed at the Nizhny Novgorod Aircraft Building Plant, Sokol (Fig. 3). To support the Dingo program, a significant amount of research was performed (more than 19 models and cells) in association with TsAGI and other state institutes. The project was successfully represented within TsAGI's advanced scientific and technical seminar which recommended that construction should commence. Experts from the Gromov Flight Research Institute stressed that in take-off modes, the safety rate of Dingo aircraft with ACLG is around 10-13 times that of helicopters and hydroplanes. With the capability to operate from airdromes, the Dingo surpasses helicopters in terms of range, speed, economic efficiency and convenience.



a) aerodynamic model b) towed model c) towed ACLG stand

Figure 3: First experimental flight model of "Dingo" aircraft

Prime Cost Comparisons

Compared with wheel-chassis aircraft, the prime cost of one Dingo flight hour revealed a 20% deficit. However, the Dingo's advantage over helicopters and hydroplanes was a 2-3 times improvement (Fig.4.A). Ratings were performed according to standard procedure and excluded conditions of the regional aerodrome environments, i.e. all aircraft took off from a concrete runway, flew through the maximal estimated range and returned to the same runway that they took off from. Prime cost estimation is made dependent on availability and condition of aerodrome surfaces. In that case, prime cost changes for different types of aircraft respectively (Fig.4.B). Operation of the Dingo within undeveloped aerodrome environments surpasses all existing types of aircraft. The economic advantage increases with the total number of take-offs and landings on natural aerodromes and different-surface grounds per year.

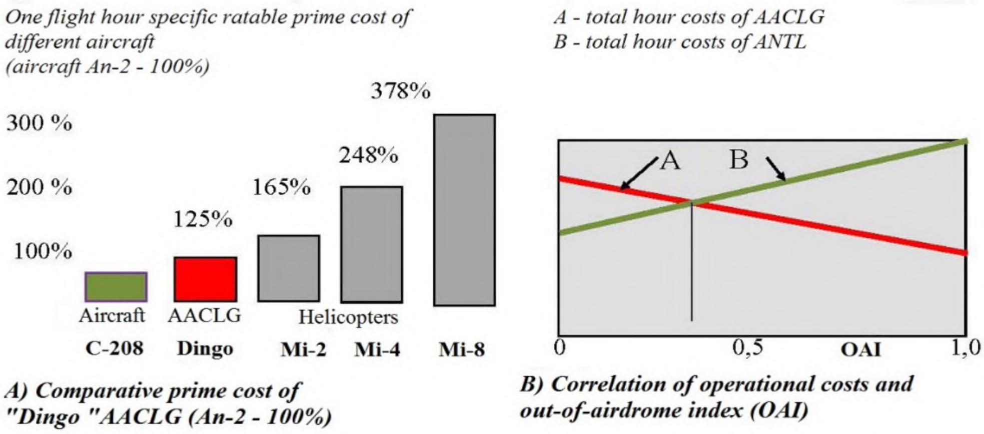


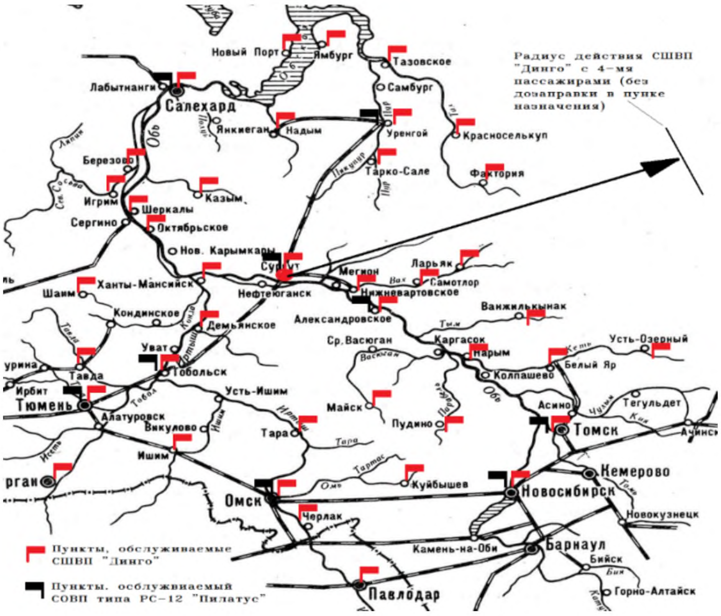
Figure 4: Comparative economic efficiency of Dingo aircraft

Legend: AACLG – Dingo aircraft, ANTL – aircraft with normal take-off and landing (wheel-chassis type Cessna Caravan); OAI – out-of-airdrome index – correlation of total amount of take-offs and landings on natural airdromes and different-surface grounds per year (water, snow, soil, ice, swamp, sand) and total amount of take-offs and landings on all types of runway (including made runway) per year (OAI=0- takeoff only from made runway, OAI=1,0- takeoff only from unequipped, unpaved, snowed and water grounds).

For instance, considering aircraft operational capabilities in regions of Western Siberia, it becomes evident that number of sites served by Dingo aircraft is ten times that served by Pilatus RS-12 aircraft. Fig.5.

It's known that as flying hours increase, the aircraft's prime cost becomes significantly lower.

Further research in association with TsAGI proves that as take-off weight increases, the mass ratio of the air-cushion significantly diminishes, eventually becoming even less than the wheel-chassis mass. By increasing aerodynamic efficiency, the ACLG-equipped aircraft can approach the ratings of the best carriers and airliners taking off from a concrete runway.



Legend:

- ***black flag*** *- sites available for RS-12;*

- ***red flag*** *- sites available for "Dingo";*

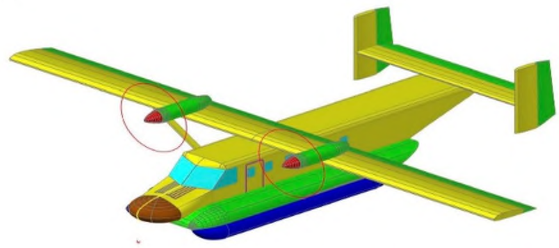
- ***black arrow*** *- action radius of Dingo with 4 passengers (no refuel at the point of destination).*

Figure 5: Sites approachability comparison for different types of aircraft

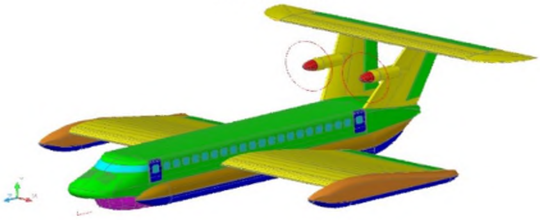
3 FURTHER DEVELOPMENT

Project researches were performed on applicability of the "early alignment principle" to a wide range of aircraft: light training aircraft, heavy carriers, and ekranoplanes (GEVs) with ACLG. Some of these projects are shown on Fig.6.

a) "Froggy-2" training single-engine aircraft with ACLG



b) Light 20-seat aircraft with ACLG for inner regional shipment (Skyvan-VP)



c) "Raketa-2M" civil, all-seasons river ekranoplane with ACLG project (110-seat)

d) "Arctica" carrier with fully-retractable ACLG railing

Figure 6: Amphibious aircraft with ACLG

Incorporating the use of amphibious aircraft fitted with ACLG will enable the capability to develop a regular speed transport network, with minimal dependence on weather and climate conditions, in regions where the costs of developing aerodromes and infrastructure, and their maintenance, are unreasonable. Furthermore, such a network can be deployed together with existing river infrastructure, independent of navigable depth and seasonal navigation restrictions.

In coalition with the experts from TsAGI, the Amphibious Transport Network (ATN) was proposed for Siberia and the Far East regions of Russia (Fig.7). At the heart of ATN lies the "transport threader", which incorporates the Baikal-Amur Mainline railway (BAM). The BAM runs entirely across Russia from West to East, crossing all of the major rivers encountered on its meridian route.

It is possible to create twenty-four-hour navigation of those rivers using the ekranoplane type "Raketa-2M" which has a cruising speed of nearly 200 kmh. The amphibious nature of the ekranoplane type of aircraft allows them to dock at the riverside stations to board and deplane passengers. Aircraft with Dingo-type ACLG will be able to connect settlements and towns lacking airdromes and river stations with major airports and ekranoplane river stations. Carriers with ACLG can transport supplies to oilrigs, mines and the like, as well as provide passenger transportation in severe climate conditions and to arctic expeditions. ACLG-equipped aircraft can perform tasks required by any agencies, including rescue operations and critical emergencies.

Figure: 7. Amphibious transport network in Russia

4 CONCLUSIONS

Considering the details that we have just discussed, it can be concluded that aircraft with Air-Cushion Landing Gear can:

1. Provide connections between regular aerodromes and distant regions;
2. Form stable, economical aviation transport supply services for regions with less-developed aerodromes and infrastructure;
3. Allow decentralization of transport flows and enhance proportional development of regional transport systems;
4. Significantly reduce costs of aerodrome system development in regions with few passenger channels and low passenger flows;
5. Reduce the burden of local air and water transport systems on regional budgets;
6. Entail multiplicative effects on economic growth and social-economic development of distant country regions.

REFERENCES

[1] Zhytomyrsky G.I. Aircraft Design. Moscow. Engineering. 1991. (In Rus.)

[2] Tikhonravov VA The Design of the Aircraft. Landing gear. Edited by VF Bolkhovitinov. M. Proceedings of MVA them. prof. N.E. Zhukovsky. 1958. (In Rus.)

[3] Khanzhonkov V.I. Aerodynamics devices hovercraft. M: Mechanical engineering, 1972. (In Rus.)

[4] Morozov VP The energy and weight characteristics of the aircraft landing gear navozdushnoy cushion and chassis Air Lubricant. Thesis for the degree of Cand. tehn. Sciences. M. MAI 1983. (In Rus.)

[5] Berdov V. Development to ensure take-off from runway damaged systems. Journal:. Foreign military review, number 2, p.62. 1982. (In Rus.)

[6] Belyaev. Amphibians and flying boats. TsAGI research report "Analysis of the structures and characteristics of domestic and foreign seaplanes" 1, 2 vol. 1991. (In Rus.)

[7] Dipl.Ing. Gerhard Morgenroth / O. Reich. Fahrwerke. / 1.Teil. Mag. Flieger revue. # 11 in 1981. p.500 - 507. / 2.Teil. Mag. Flieger revue. # 12 in 1981. p.548 - 556.

[8] PG Burdin, Zaitsev VN, police officer LR et al. The design of the aircraft. KVIAVU-Force. Kiev. 1967. (In Rus.)

[9] Maslov L.A., Petrov A.V., Svyatoduh V.K. and others. Problems aerodynamics take-off and landing strips with short and prepared runway/ Coll. "Aviation Technologies". M. TsAGI 1997. (In Rus.)

[10] Arepyev A.N. Design of light passenger aircraft. M.: MAI. 2006. (In Rus.)

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Modern Aircraft Design Goes Beyond the Classical Aerospace Engineering

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Keywords: Aircraft design course, aerospace computation, optimization, data analysis, modeling, education.

Abstract. *Aircraft design process has gone a long way from the traditional pen-and-paper approach. Designers have now relied less on the costly and time-consuming wind-tunnel experiments, and have taken advantage of the advances in computing technologies, numerical methods, and data science. Aerospace computation has now become the state-of-the-art approach for aircraft design. It is thus imperative to equip our students with the relevant background and knowledge beyond the classical aerospace engineering topics, including computational engineering, data analytics, and programming skills. Moreover, students need to be exposed to the aircraft design cycle typically applied in industry. These considerations will shape the pre-requisites and syllabus for an aircraft design course offered to university students. We need to further emphasize the importance of mathematics and programming background of students taking the course. By the end of the course, students are expected to have the fundamental knowledge and experience on a typical aircraft design process in industry. We should therefore expose students to topics outside the traditional aerospace engineering realm, including computational engineering, aviation economics (market analysis, cost estimation), and the assessment of the environmental impacts of aviation.*

1 Towards Modern Aircraft Design Process

An aircraft design process is a long and complex process that needs to be performed iteratively. This section first begins by providing an overview of the traditional aircraft design process. Next, the concept of aerospace computation is introduced, followed by the associated limitations and solutions adopted by aircraft designers nowadays.

1.1 Traditional Aircraft Design Approach

An aircraft is a complex and multidisciplinary system, with the complexity spanning across the number of parts involved, material types used, manufacturing techniques employed, operational parameters, etc. Some of the typical disciplines involved include aerodynamics, structures, engine/propulsion system, flight mission/trajectory profile, avionics, guidance and control. The complexity is further exacerbated by the interdisciplinary coupling within the system, where changing a parameter in one discipline will affect the performance of other disciplines. Increasing the wing span, for instance, might improve the overall aerodynamic performance by reducing drag, but it might in turn cause stability issues (such as flutter) and affect the structural performance of the aircraft. As such, an aircraft design process is typically done iteratively, where the configuration design, sizing, and performance evaluation keep being updated until the desired design is achieved.

An aircraft design process starts with specifying the requirements, i.e., the mission payloads and ranges that the aircraft will operate. Based on these requirements, the designers would first perform weight estimation (including takeoff gross weight, empty weight, and fuel weight), cost estimation, preliminary sizing, and configuration layout. These processes rely mostly on rough calculations, intuitive knowledge, and historical configurations and data. The designers would then iteratively refine the sizing and design until they arrive at the final design. Prior to 1960, the aerodynamic performance evaluation and thus aircraft design relied mostly on wind-tunnel experiments [1]. Richard Whitcomb, one of the most prominent aviation pioneer and aerodynamicists in the second half of the 20th century used to design airfoil sections by hand, based on his aerodynamic knowledge and data collected during wind-tunnel experiments. Nowadays, this time-consuming and costly activity can be easily replaced by running some simulation and optimization on a personal laptop. Needless to say, aerospace computation has now dominated the aircraft design field.

1.2 Aerospace Computation

Computational science has become an indispensable part of aerospace engineering. Intensive computation for simulation and optimization has been shown to be essential in designing and analyzing complex systems such as aircraft. The rapid improvements in numerical algorithms and computing techniques have brought computational methods to the aircraft industry [1, 2]. It has enabled designers to combine basic mathematics and physics into algorithms to model the physical phenomena of aircraft operations. Using computational techniques for simulation and optimization allows researchers and practitioners to model and examine phenomena that are too complex, costly, and hazardous for experimentation, and thus address problems previously deemed intractable. Computational science also makes it possible to analyze the interdependency of processes across disciplinary boundaries. Aerospace computation has now gone beyond the computational fluid dynamics (CFD) and computational structural mechanics (CSM). Starting in the late 1970s, these techniques were coupled with constrained optimizations to meet the aircraft design objectives [3, 4, 5].

Optimization is a systematic method to find the design that achieves the desired design objective, while at the same time ensuring that all constraints are satisfied. There are three main components in a design optimization procedure, namely the objective function (design goal), constraints (design restrictions), and design variables. As an illustration, we can use optimization to minimize the aircraft drag by varying the airfoil and wing geometries, while ensuring that lift, stability, and structural requirements are satisfied. Some early works in aerodynamic shape optimization included those by Hicks *et al.* [3], Hicks and Henne [4], and Constentino and Holst [5] in the late 1970s and early 1980s; and in the late 1980s by Jameson [1, 2], Shubin [6], and Shubin and Frank [7].

1.3 Current Limitations and Solutions

The advancement in aerospace computation has resulted in increased modeling fidelity, i.e., how close a model is to represent the physical phenomenon. Aerodynamic modeling, for instance, has evolved from a simple inviscid, irrotational linear potential model (1960s), nonlinear potential (1970s), solving the Euler equation (1980s), and finally the Reynolds-Averaged Navier Stokes (RANS) equation (1990s) that can model the viscous effects of the flow. The same goes to other disciplines as well. This advancement, however, comes at the expense of increased complexity and computational cost. Moreover, we can now model the interdisciplinary coupling in the aircraft system using the multidisciplinary design and optimization (MDO) framework. MDO can assist the design of complex engineering systems by accounting for the coupling in the system and automatically performing the optimal interdisciplinary trade-offs [8]. MDO has been extensively used in aircraft design applications [9, 10], especially in the design of the wing, where the coupling between aerodynamics and structures is especially important. The earliest efforts in wing aerostructural optimization used low-fidelity models for both disciplines [11, 12]. Since these early contributions, the fidelity of aerodynamic and structural models has evolved immensely, which has led researchers to develop methods for high-fidelity aerostructural optimization [13, 14, 15, 16].

Despite the aforementioned capabilities, we are still far from reaching the ultimate goal in aircraft design, which is to model the entire flight envelope of the aircraft. The required number of function evaluations to perform design analysis and optimization that cover the entire flight envelope can grow beyond the practical capacity of the available computational resources. As an illustration, the Center for Computer Applications in AeroSpace Science and Engineering at the German Aerospace Center (DLR) states that 20 million simulations are needed to include 50 flight points, 100 mass cases, 10 aircraft configurations, 5 maneuvers, 20 gusts conditions, and 4 control laws in order to accurately predict aerodynamics loads acting on an aircraft throughout its flight envelope [17].

As a step to consider the entire flight operating envelope in assessing aircraft performance, we first need to be able to perform the detailed mission analysis of an aircraft operation. A mission analysis would provide a platform to combine the different aspects of aircraft operations, including aerodynamics, structures, flight mission/trajectory analysis, engine/combustion modeling, atmospheric modeling, and aeroacoustics. Moreover, we also need to know about the aircraft mission data, or operational statistics of the air traffic. Needless to say, performing detailed mission analyses using high-fidelity models would be computationally intractable. The computational burden would be even higher if we consider the uncertainty in the system for a more realistic analysis. There are many sources of uncertainty in aerospace modeling, such as in mission analysis phase (e.g., the variability of mission needs and requirements), in design phase (e.g., model input uncertainty, model uncertainty, model error), and in operation phase (e.g., fuel price, demand in air transportation). Only when these uncertainties are properly accounted for would we be able to have a thorough and in-depth aircraft performance evaluation.

Due to these limitations, aircraft designers typically assume simplified physics and operations in the analyses and optimizations in a deterministic setting, which will be described briefly. The fuel burn computation, for instance, is often done by employing the classical Breguet range equation [18] instead of by performing the detailed mission analysis [19, 20]. Using this equation, however, does not properly model the takeoff, climb, and descent segments [21]. Simple fuel fractions [20] or empirical approximation functions [22] are often used for these segments. The expensive computational cost restricts the number of flight conditions considered in the optimization problems. Therefore, the designers typically focus only on optimizing the aircraft performance at its nominal condition (e.g., nominal cruise Mach number and altitude). Early work in wing optimization focused on drag minimization with respect to aerodynamic shape considering a single flight condition [23, 24, 25, 26]. However, single-point optimization has the tendency to produce designs with optimal performance under the selected flight condition at the expense of serious performance degradation under off-design conditions [27]. Drela [28] argued that single-point drag minimization is insufficient to embody the real design requirements of an airfoil. Considering multiple flight conditions in aerodynamic shape optimization problems has thus become increasingly more common. Jameson [1] pioneered this effort, seeking a compromise design by taking the sum of cost functions for several design points. The most common approach in multipoint optimization formulation is the composite objective function, by taking the weighted sum of objective function (typically drag coefficient C_D) over several flight conditions [29]. The multipoint optimization results have been consistently shown to be superior to those of single-point optimizations, with more consistent performance gain across all flight conditions considered [1, 27, 28, 30, 31]. In the multipoint objective function formulation, the biggest challenge is to find the most suitable operating points to be sampled, which is not apparent *a priori*. Also, the relative emphasis (weight) associated with each flight condition is either arbitrary or based on the designer's prior experience [27, 28]. Lyu *et al.* [32] and Kenway and Martins [16] assigned equal weights to all five points considered in the optimization cases. Buckley and Zingg [33] employed an integration, or quadrature, rule to formulate a weighted-integral objective function in their multipoint optimization problems. The problem with the aforementioned restrictions and simplification is that there is no guarantee that they produce results that reflect an optimum real-world performance.

Surrogate modeling has also been commonly used to reduce the cost and time of the computational procedure by providing low-cost substitutes to replace expensive evaluations of the original physics-based models [34]. A surrogate model (*metamodel* [35] or *model of models* [36]) uses mathematical models to provide a simpler approximation of a physical system, thereby reducing the computational expenses of analysis and optimization [35, 37]. Surrogate models have previously been shown to assist various optimization procedures in aerospace engineering. Chung and Alonso [38, 39] used a gradient-enhanced kriging (GEK) method in a supersonic business jet design optimization, Toal and Keane [40] used a cokriging method to perform a multipoint drag minimization, Zimmermann and Görtz [41] developed a proper orthogonal decomposition (POD) subspace restricted least squares model to solve the governing fluid flow equations.

2 Incorporating Mission Data to Aircraft Design

To have a design problem formulation that truly reflects aircraft operation, the author incorporated actual flight mission data in the derivation of optimization problems. In particular, multipoint optimizations were performed where a rational strategy was derived to systematically select the points and weights used in the composite objective function. The derivation was done based on the actual mission requirements and how the aircraft operates during those missions. The benefits of incorporating data in the problem formulation as compared to optimizing the aircraft performance at its nominal condition only are obvious in the results, which will be further elaborated shortly.

To obtain a set of missions that is representative of the actual operations of a given aircraft model, the Bureau of Transportation Statistics (BTS) flight database [1] is consulted. This flight database provides information on the payload and range of each flight mission. In particular, payload and range data for all Boeing 777-200ER in 2011 that took off from the United States, landed in the United States, or both. These data consist of a set of 101 159 flights for which the payload-range frequency histogram is shown in Figure 1. The black circle refers to the nominal mission parameter used for the single-point optimization.

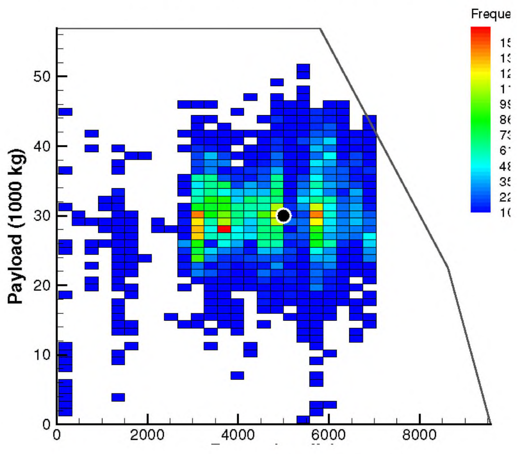
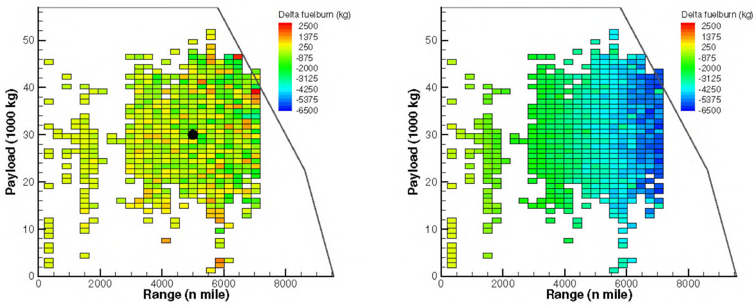


Figure 1: Histogram of 101 059 flights for the Boeing 777-200ER aircraft and its payload-range envelope.

[1] TranStats, Bureau of Transportation Statistics http://www.transtats.bts.gov/

To find the flight-condition distribution, these flight missions are analyzed using the surrogate-based mission analysis procedure developed by the author [42]. 529 representative missions are selected, which are shown as the histogram bins in Figure 1. This mission analysis procedure is a computationally efficient and accurate procedure that can emulate the different flight conditions experienced by the aircraft during different mission phases (climb, cruise, and descent).

The first multipoint optimization problem was performed to minimize the aggregate fuel burn of all flight missions shown in Figure 1. This problem was converted into a multipoint one through the linearization of fuel burn computation with respect to drag forces and structural weight. The optimization considered a coupled aerostructural system, to take into account the aerostructural coupling and tradeoff. Figure 2 present the comparison between the described multipoint and single-point optimization (where only the nominal condition was considered). In particular, the color in each bin refers to the fuel-burn reduction obtained with the optimized configuration, as compared to the baseline configuration. It is clear to see that the multipoint optimized configuration resulted in a consistent fuel burn reduction across all flight conditions considered, whereas in the single-point optimization case some flight missions actually burned more fuel using the optimized configuration; this result is clearly undesirable. The consistent fuel burn reduction in the multipoint optimization cases translated into a higher aggregate fuel burn reduction, 6.6%, which was notably higher than that of the single point case, 1.7%. Further details and results of this optimization problem can be found in [43].



(a) Single-point optimization

(b) Multipoint optimization

Figure 2: Distribution of fuel-burn change for individual missions in the payload-range diagram. The multipoint optimization consistently reduces fuel burn for all representative missions, which is not achieved by the single-point optimization.

In a multipoint aerodynamic shape optimization problem performed by the author [42], the flight-condition distribution generated from performing mission analyses on the representative flight missions was used in the estimation of the expected value of drag. Estimating the expected value via numerical integral approximation gave way to the multipoint formulation of the objective function. The expected value of drag was computed considering the variation of Mach number and lift coefficient, to represent the flight condition variability. This multipoint formulation again resulted in a configuration with a more consistent performance gain (i.e., drag reduction) than that of the single-point optimization case. Moreover, the estimated expected value of drag reflected the actual distribution more closely than when no data were used in deriving the objective function formulation. These two multipoint optimization examples yield aircraft configurations that truly reflect how aircraft actually operate in the real-world applications, which demonstrate the effectiveness of incorporating actual aircraft flight-mission data in the aircraft design process.

3 Required Skillsets of Aircraft Designers

The discussions above illustrate how designers need to acquire skills beyond the classical aerospace engineering to further advance the modern aircraft design process. In particular, they need to be adept in computational science and engineering, programming, and data analytics or information technology; each of which will be briefly discussed below.

3.1 Computational Science and Engineering

Computational science refers to the development of technologies pertaining to modeling and optimization procedures. It is important to distinguish it from computer science, which only focuses on the development of computer technologies. To perform any numerical analyses and optimization in the aircraft design process, a strong mathematical background is required. Some topics in mathematics that are often used and important in the aircraft design process include, but not limited to: linear algebra, numerical simulation, partial differential equations (PDE), integral equations, and sparse algorithms. The aforementioned skills are mostly required in the modeling phase. At the next level, designers need to master optimization methods to formulate the aircraft design problem as an optimization problem. Further, knowledge in surrogate modeling will come in handy when approximations are required at any stages of design and optimization procedures. In a complex multidisciplinary system, designers are often required to perform sensitivity studies, i.e., to identify the key drivers in the design outputs, as well as tradeoff analyses, i.e., to see how different parameters interact with each other. To account for the system uncertainty, the designers need to be familiar with stochastic modeling and uncertainty quantification (UQ) techniques.

3.2 Programming skills

There exist some dedicated software developed to assist aircraft design, be it single-disciplinary analysis tools or integrated aircraft design tools. NASTRAN [2] was one of the early finite element codes developed for structural mechanics. XFoil [3] was designed by Prof. Mark Drela from MIT to perform design and analysis of subsonic airfoils. XFoil can be used in wing design by means of the XFLR5 software [4]. For integrated aircraft design software, there are, for instance, OpenVSP [5], Advanced Aircraft Analysis (AAA) [6], and Piano [7]. Piano is a professional commercial aircraft design tool with capabilities including the assessment of environmental impacts of the aircraft operation. `pyACDT` developed by Henderson *et al.* [44] and the Program for Aircraft Synthesis Studies (PASS) [45] are two examples of conceptual design tools that can analyze aircraft performance that can be coupled with optimization tools for aircraft design optimization.

These dedicated software are user-friendly, but might be limited in terms of flexibility. The designers might want to include some features not provided by those software. In which case, they need to write their own codes. Python-wrapped fortran codes have been proven to be effective [31, 46, 47, 48]. Fortran offers significantly faster computations than Python to perform the computationally intensive parts, while Python provides a more practical user scripting interface that uses convenient class objects and also enables visualization tools. Using Python at the scripting level also facilitates the integration of the different Fortran modules.

Due to the intensity and long computational time, aircraft modeling and optimization are often done using parallel computing technologies. The multipoint aerostructural optimization problem previously completed

[2] http://www.autodesk.com/products/nastran/overview
[3] http://web.mit.edu/drela/Public/web/xfoil/
[4] http://www.xflr5.com/xflr5.htm
[5] http://www.openvsp.org/
[6] http://www.darcorp.com/Software/AAA/
[7] http://www.lissys.demon.co.uk/index2.html

by the author used 1049 processors [43], and the multipoint aerodynamic shape optimization used 480 processors [31]. Both computations were performed on the General Purpose Cluster (GPC) supercomputer at the SciNet High Performance Computing (HPC) Consortium, which was funded by the Canada Foundation for Innovation [49]. The use of supercomputer and cluster computing technologies has become more common. There are some large ones in the region such as the national supercomputer center in Shenzhen [8] and Tianjin [9].

3.3 Data Analytics/Information Technology

Advances in computing and storage systems have greatly facilitated the gathering and sharing of large amount of data. The Bureau of Transportation Statics (BTS) [10], for instance, makes a large amount of transportation data (including aircraft operation) publicly available. These data contain useful information on how the aircraft actually operate in real world, and thus can be used to further enhanced the effectiveness of aircraft design process, as demonstrated in the multipoint optimization cases previously discussed in Section 2. As such, knowledge and skills in data analytics and information technology would be essential, to enable incorporating this abundance of data into the analysis and design processes. The use of statistical machine learning can help make sense of the vast amount of data, i.e., to identify patterns in data, statistical parameters, principal components, etc.

4 Modern Aircraft Design Course Syllabus

I hope that this paper has given a glimpse of the landscape of modern aircraft design, and how it has gone beyond the classical aerospace engineering. Advances in computing technologies, storage systems, and data science have expanded the scope of what an aircraft designer can do. They can now perform more computationally intensive procedures in reasonable resources and time, and make use of the vast amount of available data to complement the aircraft design process. Some of the future aircraft designers will start from our classrooms. Therefore, it is important to ensure that our students are well-equipped with the skills and knowledge required to be competent aircraft engineers and designers. This section will briefly discussed how to shape an aircraft design course for university students, based on our previous discussion.

In order to expose students to the common aircraft design practices in industry, we will guide them to emulate the typical design cycle through a design project. The projects will be done in groups, since teamwork is an essential aspect in the design process. Within a project team, each student will be assigned a different subsystem. In addition to mastering their specific topic, they will also need to be able to work together as a team to ensure the compatibility of the different subsystems and to achieve the common design goal. In doing so, they will learn to apply the systems engineering approach to design a system as complex as an aircraft.

To imitate the complete design cycle, despite in a much smaller scale, the students need to perform the market research analysis, to formulate the target mission requirements of the aircraft they are going to design. As we have previously discussed, setting the mission requirements (e.g., whether it is a long-haul or short-haul aircraft) is the first step in a design process and will determine the configurations and designs of the aircraft. Students also need to be aware of the key drivers in the design of future aircraft configurations, as they will greatly affect the objective and constraints in the optimization problem formulation. Right now, the growing concerns of the environmental impacts of aviation (emissions, local air quality, and noise) and fuel economy, coupled with the increasing air traffic activities, demand for fuel efficient, environmentally-friendly aircraft [31, 50, 51]. Assessing the environmental impacts of aviation has thus become an essential part in the design, and students need to be exposed to this aspect.

[8] http://www.nsccsz.gov.cn/en

[9] http://www.nscc-tj.gov.cn/en/

[10] http://www.rita.dot.gov/bts/home

During the course of the design project, students will go through the aircraft design process and perform the required analyses. The typical process starts with weight estimation, preliminary sizing, configuration layout (including fuselage, wings, landing gears, stability components, and propulsion system), and followed by sizing refinement to achieve the final design. This will require the coverage of basic aerodynamics, structures, flight performance and stability, propulsion topics in class, which could be considered as the more *classical* topics in aerospace engineering. In addition to the engineering and computational aspects of aircraft design, we need to introduce students to the aviation economics. This module would equip students with knowledge on the economic aspects in airline industry, including its market, technology readiness level, and the supply chain managements. Next, the students need to have fundamental knowledge on the aircraft life-cycle cost analysis as well as cost estimation, including the aircraft unit price, operations, and maintenance costs. In light of the growing environmental concerns of aviation, students need to be aware of its economic implications.

There are essentially three basic skills that every aerospace engineering student should have, namely the mathematics skills, coding skills, and communication skills. Strong mathematics and coding background will enable students to manipulate computational models in simulations and optimization procedures, and should be made pre-requisites for the aircraft design class. It is clear from our previous discussions that aerospace computation is the way to go to design future aircraft. Students will be introduced to the available optimization techniques, including the multidisciplinary design and optimization (MDO) methods, even if they do not perform a full optimization in their class project. To keep up with the current trend and common practices, the students will get the chance to use the state-of-the-art dedicated software to complete the design project.

At the completion of the course project, the students will be required to complete a project report and do an oral presentation in front of the instructor and their classmates. The report should include a detailed and clear description of their proposed design, and the computer-generated 3D drawings for the overall layout and components. The students have to present clearly the rationale behind their designs (i.e., how they come up with the proposed designs), and any relevant decision making and risk-benefit analyses whenever applicable. In additional to the technical assessment, their communication skills (both oral and written), including the structures, clarity, and completeness, will contribute to the final scores as well.

References

[1] Jameson, A., "Automatic Design of Transonic Airfoils to Reduce the Shock Induced Pressure Drag," *Proceedings of the 31st Israel Annual Conference on Aviation and Aeronautics*, Technion-Israel, Haifa, Israel, 1990, pp. 5–17.

[2] Jameson, A., "Aerodynamic Design via Control Theory," *Journal of Scientific Computing*, Vol. 3, No. 3, 1988, pp. 233–260.

[3] Hicks, R. M., Murman, E. M., and Vanderplaats, G. N., "An assessment of airfoil design by numerical optimization," Tech. rep., NASA TM X-3092, July 1974.

[4] Hicks, R. M. and Henne, P. A., "Wing Design by Numerical Optimization," *Journal of Aircraft*, Vol. 15, July 1978, pp. 407–412.

[5] Constentino, G. B. and Holst, T. L., "Numerical Optimization Design of Advanced Transonic Wing Configurations," Tech. rep., NASA TM 85950, 1984.

[6] Shubin, G. R., "Obtaining Cheap Optimization Gradients from Computational Aerodynamics Codes," International Paper AMS-TR-164, Boeing Computer Services, June 1991.

[7] Shubin, G. R. and Frank, P. D., "A Comparison of the Implicit Gradient Approach and the Variational Approach to Aerodynamic Design Optimization," International Paper AMS-TR-164, Boeing Computer Services, June 1991.

[8] Martins, J. R. R. A. and Lambe, A. B., "Multidisciplinary Design Optimization: A Survey of Architectures," *AIAA Journal*, 2013. doi:10.2514/1.J051895, (In press).

[9] Antoine, N. E. and Kroo, I. M., "Framework for Aircraft Conceptual Design and Environmental Performance Studies," *AIAA Journal*, Vol. 43, No. 10, Oct. 2005, pp. 2100–2109. doi:10.2514/1.13017.

[10] Henderson, R. P., Martins, J. R. R. A., and Perez, R. E., "Aircraft Conceptual Design for Optimal Environmental Performance," *The Aeronautical Journal*, Vol. 116, No. 1175, Jan. 2012, pp. 1–22.

[11] Haftka, R. T., "Optimization of Flexible Wing Structures Subject to Strength and Induced Drag Constraints," *AIAA Journal*, Vol. 15, August 1977, pp. 1101–1106. doi:10.2514/3.7400.

[12] Grossman, B., Gurdal, J., Strauch, G. J., Eppard, W. M., and Haftka, R. T., "Integrated Aerodynamic/Structural Design of a Sailplane Wing," *Journal of Aircraft*, Vol. 25, No. 9, 1988, pp. 855–860. doi:10.2514/3.45670.

[13] Martins, J. R. R. A., Alonso, J. J., and Reuther, J. J., "Aero-Structural Wing Design Optimization Using High-Fidelity Sensitivity Analysis," *Proceedings of the CEAS Conference on Multidisciplinary Aircraft Design and Optimization*, edited by H. Hölinger, DGLR, Bonn, June 2001, pp. 211–226.

[14] Martins, J. R. R. A., Alonso, J. J., and Reuther, J. J., "A Coupled-Adjoint Sensitivity Analysis Method for High-Fidelity Aero-Structural Design," *Optimization and Engineering*, Vol. 6, No. 1, March 2005, pp. 33–62. doi:10.1023/B:OPTE.0000048536.47956.62.

[15] Kenway, G. K. W., Kennedy, G. J., and Martins, J. R. R. A., "Scalable Parallel Approach for High-Fidelity Steady-State Aeroelastic Analysis and Derivative Computations," *AIAA Journal*, Vol. 52, No. 5, 2014, pp. 935–951. doi:10.2514/1.J052255.

[16] Kenway, G. K. W. and Martins, J. R. R. A., "Multi-point High-fidelity Aerostructural Optimization of a Transport Aircraft Configuration," *Journal of Aircraft*, Vol. 51, 2014, pp. 144–160. doi:10.2514/1.C032150.

[17] for Computer Applications in AeroSpace Science, C. and Engineering, "Top Level Technology in Numerical Simulation for Aircraft Design," PowerPoint presentation, Deutsches Zentrum für Luft- und Raumfahrt (DLR), 2010.

[18] Breguet, L., "Calcul du Poids de Combustible Consummé par un Avion en Vol Ascendant," *Comptes Rendus Hebdomodaires des Séances de l'Académie des Sciences*, Vol. 177, July 1923, pp. 870–872.

[19] Lee, J. J., *Historical and Future Trends in Aircraft Performance, Cost, and Emissions*, Master's thesis, Aeronautics & Astronautics Department and Technology & Policy Program, Massachusetts Institute of Technology, September 2000.

[20] Roskam, J., *Airplane Design Part I: Preliminary Sizing of Airplanes*, Roskam Aviation and Engineering Corporations, Ottawa, KS, 1985.

[21] McCormick, B. W., *Aerodynamics, Aeronautics, and Flight Mechanics*, John Wiley & Sons, New York, US, 1979.

[22] Lee, H. and Chatterji, G. B., "Closed-Form Takeoff Weight Estimation Model for Air Transportation Simulation," *10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference*, Fort Worth, TX, Sept 13–15 2010. doi:10.2514/6.2010-9156, AIAA 2010-9156.

[23] Anderson, W. K. and Venkatakrishnan, V., "Aerodynamic Design Optimization on Unstructured Grids with a Continuous Adjoint Formulation," *Computers and Fluids*, Vol. 28, No. 4, 1999, pp. 443–480. doi:10.1016/S0045-7930(98)00041-3.

[24] Nadarajah, S. and Jameson, A., "A comparison of the continuous and discrete adjoint approach to automatic aerodynamic optimization," *AIAA 38th Aerospace Sciences Meeting and Exhibit*, Reno, NV, January 2000, AIAA 2000-0667.

[25] Reuther, J., Jameson, A., Farmer, J., Martinelli, L., and Saunders, D., "Aerodynamic shape optimization of complex aircraft configurations via an adjoint formulation," *34th Aerospace Sciences Meeting and Exhibit*, Reno, NV, January 1996. doi:10.2514/6.1996-94, AIAA 96-0094.

[26] Samareh, J., "Aerodynamic Shape Optimization Based on Free-form Deformation," *10th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference*, Vol. 6, 2004, pp. 3672–3683. doi:10.2514/6.2004-4630.

[27] Cliff, S. E., Reuther, J. J., Saunders, D. A., and Hicks, R. M., "Single-Point and Multipoint Aerodynamic Shape Optimization of High-Speed Civil Transport," *Journal of Aircraft*, Vol. 38, No. 6, 2001, pp. 997–1005. doi:10.2514/2.2886.

[28] Drela, M., "Pros and Cons of Airfoil Optimization," *Frontiers of CFD 1998*, edited by D. Caughey and M. Hafez, World Scientific, 1998, pp. 363–381.

[29] Nemec, M., Zingg, D. W., and Pulliam, T. H., "Multipoint and Multi-Objective Aerodynamic Shape Optimization," *AIAA Journal*, Vol. 42, No. 6, June 2004, pp. 1057–1065.

[30] Reuther, J. J., Jameson, A., Alonso, J. J., Rimlinger, M. J., and Saunders, D., "Constrained Multipoint Aerodynamic Shape Optimization Using an Adjoint Formulation and Parallel Computers, Part 2," *Journal of Aircraft*, Vol. 36, No. 1, 1999, pp. 61–74.

[31] Liem, R. P., *Multimission Fuel-Burn Minimization in Aircraft Design: A Surrogate-Modeling Approach*, Ph.D. thesis, University of Toronto, 2015.

[32] Lyu, Z., Kenway, G. K. W., and Martins, J. R. R. A., "RANS-based Aerodynamic Shape Optimization Investigations of the Common Research Model Wing," *Proceedings of the AIAA Science and Technology Forum and Exposition (SciTech)*, National Harbor, MD, January 2014. doi:10.2514/6.2014-0567, AIAA 2014-0567.

[33] Buckley, H. P. and Zingg, D. W., "Approach to Aerodynamic Design Through Numerical Optimization," *AIAA Journal*, Vol. 51, No. 8, August 2013, pp. 1972–1981. doi:10.2514/1.J052268.

[34] Giannakoglou, K. C., Papadimitriou, D. I., and Kampolis, I. C., "Aerodynamic shape design using evolutionary algorithms and new gradient-assisted metamodels," *Computer Methods in Applied Mechanics and Engineering*, Vol. 195, 2006, pp. 6312–6329. doi:10.1016/j.cma.2005.12.008.

[35] Simpson, T. W., Booker, A. J., Ghosh, D., Giunta, A. A., Koch, P. N., and Yang, R. J., "Approximation methods in multidisciplinary analysis and optimization: A panel discussion," *Structural and Multidisciplinary Optimization*, Vol. 27, 2004, pp. 302–313.

[36] Jin, R., Chen, W., and Simpson, T. W., "Comparative studies of metamodelling techniques under multiple modelling criteria," *Structural and Multidisciplinary Optimization*, Vol. 23, 2001, pp. 1–13. doi:10.1007/S00158-001-0160-4.

[37] Sobieszczanski-Sobieski, J. and Haftka, R. T., "Multidisciplinary aerospace design optimization: Survey of recent developments," *Structural Optimization*, Vol. 14, 1997, pp. 1–23. doi:10.1007/BF01197554.

[38] Chung, H. S. and Alonso, J. J., "Design of a Low-Boom Supersonic Business Jet Using Cokriging Approximation Models," *9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, Atlanta, GA, September 2002, AIAA Paper 2002–5598.

[39] Chung, H. S. and Alonso, J. J., "Using Gradients to Construct Cokriging Approximation Models for High-Dimensional Design Optimization Problems," *9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, Reno, NV, January 2002, AIAA Paper 2002–0317.

[40] Toal, D. J. J. and Keane, A. J., "Efficient Multipoint Aerodynamic Design Optimization via Cokriging," *Journal of Aircraft*, Vol. 48, No. 5, September–October 2011, pp. 1685–1695. doi:10.2514/1.C031342.

[41] Zimmermann, R. and Görtz, S., "Non-linear reduced order models for steady aerodynamics," *Procedia Computer Science*, Vol. 1, 2010, pp. 165–174. doi:10.1016/j.procs.2010.04.019.

[42] Liem, R. P., Mader, C. A., and Martins, J. R. R. A., "Surrogate Models and Mixtures of Experts in Aerodynamic Performance Prediction for Mission Analysis," *Aerospace Science and Technology*, Vol. 43, 2015, pp. 126–151. doi:10.1016/j.ast.2015.02.019.

[43] Liem, R. P., Kenway, G. K. W., and Martins, J. R. R. A., "Multimission Aircraft Fuel Burn Minimization via Multipoint Aerostructural Optimization," *AIAA Journal*, Vol. 53, No. 1, 2015, pp. 104–122. doi:10.2514/1.J052940.

[44] Henderson, R. P., Martins, J. R. R. A., and Perez, R. E., "Aircraft Conceptual Design for Optimal Environmental Performance," *The Aeronautical Journal*, Vol. 116, 2012, pp. 1–22.

[45] PASS, "Program for Aircraft Synthesis Studies Software Package," Desktop Aeronautics, Inc., Palo Alto, CA, 2005.

[46] Peterson, P., Martins, J. R. R. A., and Alonso, J. J., "Fortran to Python Interface Generator with an Application to Aerospace Engineering," *Proceedings of the 9th International Python Conference*, Long Beach, CA, Jan. 2001.

[47] Kenway, G. K. W., Kennedy, G. J., and Martins, J. R. R. A., "Scalable Parallel Approach for High-Fidelity Steady-State Aeroelastic Analysis and Derivative Computations," *AIAA Journal*, Vol. 52, No. 5, May 2014, pp. 935–951. doi:10.2514/1.J052255.

[48] Perez, R. E., Jansen, P. W., and Martins, J. R. R. A., "pyOpt: a Python-Based Object-Oriented Framework for Nonlinear Constrained Optimization," *Structural and Multidisciplinary Optimization*, Vol. 45, No. 1, 2012, pp. 101–118. doi:10.1007/s00158-011-0666-3.

[49] Loken, C., Gruner, D., Groer, L., Peltier, R., Bunn, N., Craig, M., Henriques, T., Dempsey, J., Yu, C.-H., Chen, J., Dursi, L. J., Chong, J., Northrup, S., Pinto, J., Knecht, N., and Zon, R. V., "SciNet: Lessons Learned from Building a Power-efficient Top-20 System and Data Centre," *Journal of Physics: Conference Series*, Vol. 256, No. 1, 2010, pp. 012026. doi:10.1088/1742-6596/256/1/012026.

[50] IPCC, "IPCC Special Reports on Climate Change," *Aviation and the Global Atmosphere*, edited by J. Penner, D. Lister, D. Griggs, D. Dokken, and M. McFarland, Cambridge University Press, UK, 1999, pp. 1–23.

[51] ICAO, "Aviation and Climate Change," International Civil Aviation Organization (ICAO) Environmental Report, 2010.

THE CONFERENCE "AEROSPACE TECHNOLOGY, MODERN MATERIALS AND EQUIPMENT" – IS THE PLATFORM FOR THE DEVELOPMENT OF AVIATION ENGINEERING EDUCATION IN RUSSIA

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Abstract. *This article provides information about the history, organizers, and participants of the conference in the framework of exhibition Aerospace technologies, modern materials and equipment - ACP Conference. It reviews the most interesting reports on the subject of Design in the Field of Education, and perspectives of the conference, as well as its role in the establishment of international relations, including with China.*

The Republic of Tatarstan has great industrial potential and is one of the leading regions in the field of aerospace technology in Russia. The aerospace complex of Tatarstan consists of a large number of enterprises and research organizations which are well-know throughout Russia and all over the world, and include such entities as; Kazan Aviation Factory, Kazan Motor Production Association, Kazan Helicopter Factory and others. In this regard, it is not surprising that Kazan, the capital of the Republic of Tatarstan, every two years becomes the center of attraction for all of the aviation industry of the Russian Federation, and holds one of the largest exhibitions devoted to aerospace technology in Russia: Aerospace Technologies, Modern Materials and Equipment - ACP.

An iternational specialized exhibition Aerospace Technologies, Modern Materials and Equipment - ACP was held in Kazan in for the first time in 2002. The exhibition brought together about 70 companies from Russia, Ukraine, Belarus, and was visited by more than 6000 people. Every year the geography of exhibitors has expanded, so during different time periods the exhibition has been attended by representatives from Germany, France, Switzerland, Kazakhstan, Lithuania, Syria and the USA. Various research institutes, design bureaus, enterprises and companies from Russia and foreign countries have taken the opportunity to demonstrate their achievements. In 2014, the exhibition was attended by about 100 companies from 16 Russian cities: Moscow, Saint Petersburg, Almetyevsk, Armavir, Dubna, Ekaterinburg, Chrysostom, Izhevsk, Irkutsk, Kazan, Karachev, Kirovo-Chepetsk, Lipetsk, Perm, Samara, Tomsk. Companies included the Rostec Corporation, United Aircraft Corporation, Obronprom Corporation, and large research centers such as Central Institute of Aviation Motor Development, the All-Russian Scientific Research Institute of Aviation Materials, the Central Aero-hydrodynamic Institute and many others participated in and visited the exhibition. Companies representing the products of 11 countries have also participated in ACP: Belgium, France, Germany, Israel, Italy, Norway, Belarus, USA, France, Switzerland and Sweden. In 2014 the exhibition was visited by a delegation from the China Aerospace Science and Industry Corporation (CASIC) and Aerosun Corporation [1].

Traditionally, the international scientific-practical conference on aerospace technologies is held within the framework of the business program of ATC. The Conference is organized in sections: "Aircraft Engineering", "Design, Engineering and Production", "Engines and Power Plants", "Avionics, Equipment and Control systems," "Radio-technical Systems and Aircraft Complexes", "Information Technologies in the Aerospace Industry", "Financial and Economic Aspects of Development of Aerospace Complex of Russia and the Republic of Tatarstan" and "Training of Personnel for the Aerospace Industry". Usually, the participants of the conference are the heads of leading research centers, scientific and technical complexes, scientists and specialists of higher educational institutions, research institutes, design organizations, aerospace centers of Russia and other countries. The President of United Aircraft Corporation, the Director of Helicopters of Russia, the Director of the Central Aero-hydrodynamic Institute and many others have made plenary reports in the framework of the conference.

Modern technologies in the aviation and space industries, and innovations in aviation that are presented at exhibitions like ACP are the results of the work of highly skilled engineers and personnel, so the question of training of high-quality personnel for high-tech enterprises is a key question for discussion at such exhibitions and conferences. In this context, it is obvious that for many years the ACP conference is an effective communication platform for professional discussions of the main issues of aviation engineering education in Russian aviation universities.

At the conference, the questions of modern requirements for training workers for the aerospace industry, and new educational technologies are the main issues of plenary and section reports. Within the framework of the conference, meetings of heads of enterprises of the aerospace industry, rectors and vice-rectors of universities, heads of personnel services of enterprises, and experts in the field of education are held to discuss new methods, innovative educational training and retraining technologies. Questions as to what competencies should graduates possess and how to develop those competencies are discussed during the round tables meetings.

During the conferences, a very wide range of issues pertaining to personnel training for the aerospace industry was discussed, so let’s note the most interesting questions and reports that were made within the last two ACP conferences.

Today in Russia the system of higher education allows for single-level training graduates (duration 5 and 5.5 years) and also for a two-level education system with the assignment of graduate Bachelor's degree (4-year training) and master's degree (duration 1-2 years) after receiving a bachelor's degree or professional qualification. Every year, the two-level training system is expanding within the higher education institutions in Russia, including universities which train engineers for the aerospace industry. However, the appropriateness of the two-level system of training for aerospace engineering personnel, is the topic that is causing a lot of disputes. The weak point of the two-level education system and its implementation in the training of specialists for the aerospace industry, is the lack of clear advantages in comparison to the pre-existing system of education. This theme is the most discussed topic during the round-table sections of the conference.

The implementation of distance learning in the field of training for aerospace industry is also very controversial and an interesting topic for discussion. The modern stage of development of engineering is characterized by the increased demands for mobile professional specialists who are able to realize themselves in the constantly changing environment, so the application of distance learning for training and retraining, obviously, would be a tool for solving problems of this kind. However, the effectiveness of distance learning technologies in the narrow technical practice-oriented disciplines remains the big question. For example, in [2], the role of distance learning in modern engineering education is considered, including techniques of distance laboratory practice, as well as an analysis of the effectiveness of distance laboratory work. The advantages of distance learning are mentioned: *"The role of distance education is constantly increasing due to the development of information and telecommunication technologies. The advantages of this form of training are ease of access to the educational material, the opportunity to study at a convenient time and regardless of where they live, availability for all persons, regardless of employment at work, health and so on."*

Also the factors that can prevent the spreading of distance education technologies were noted. *"The limitations of the introduction of distance learning in engineering specializations are outdated teaching techniques and instruments"*. In the paper it was pointed out that the distance learning technologies should be used in teaching technical disciplines only in conjunction with the complex of classroom laboratory works involving the teacher. *"The present level of development of information technologies has opened up wide perspectives and opportunities for the study of phenomena that occur in the technical devices and systems. These phenomena can be modeled in different computing environments or studied by the actual devices and systems using the appropriate hardware and software. A rational combination of traditional laboratory works and distance technologies is a priority for improvement of engineering education "*.

In [3], a monitoring system which is necessary to control, estimate the quality of, and value the correctness of the student's distance laboratory practice in technical disciplines, is presented. *"The system enables you to record statistics and the timing of each student, as well as to make the quality analysis of the implementation of the practical detailing in chronological order of the experiment sequence, set of input data and value their correctness."*

In [4], the questions of integration of the educational information system for training and retraining of engineers are discussed. The authors recommend *"the widespread introduction of digital educational services for all education institutions to train qualified specialists in the field of engineering and to ensure the effective use of available resources of* *educational institutions and enterprises seems appropriate use of the modular data center"*. In the paper it is noted that *"in the framework of this approach, a real integration of education, research and production information environments of universities and enterprise, its subsequent advanced development for the real competitiveness of the industry can be implemented. A network of data centers should provide information and logistical cooperation of all subjects of the education system. An important feature of data centers is providing all activities in the field of training and retraining: educational work, management, extracurricular activities, control"*.

Modernization of professional education is one of the priority directions of development of Russian education. According to the President of the United Aircraft Corporation Yury Slyusar: *"For the successful development of the aircraft industry today it is necessary to introduce modern educational standards and to train professional staff in this way, so that young professionals are to be ready for work immediately after the end of education"*. For an effective functioning of the system of personnel training for the aerospace industry it is necessary to provide integrity to the systems of science, education and industry, and to develop the concept of continuing professional education and the concept of practice-oriented learning technologies. The organization of resource centers that include several educational institutions that will have the opportunity to exchange among institutions material, technical, educational and human resources intended for the development of modern professional technology is an obvious requirement [5]. Also, the questions of the implementation of a dual training system is considered, the scientific reasoning, testing, and then the introduction, the development of dual forms of training in college and distribution in the system of professional education are mentioned.

A part of the section reports the issues of special contract training, as well as issues of additional retraining were noticed [6].

In [7], cooperation with the European aerospace clusters, training, issues of innovative educational technologies of the world's top universities, as well as perspective directions of international scientific and technological co-operation are studied. The issues of realization of joint international training programs in the aerospace industry, the development and implementation of competence centers in the field of training for the aerospace industry, the development and implementation of joint educational programs in the field of aviation are considered. It was noted that the priority is to *"create a union of highly qualified engineers, who are well practiced in foreign languages, are able to navigate in the stream of the global information network, and are able to find new modern technological solutions and achievements in the field of their professional interests"*.

International cooperation in the field of training highly qualified engineering personnel for the aviation industry, in our view, is today one of the most perspective areas of cooperation between Russia and China. Today Russia and China are constantly increasing the rate of cooperation and expanding the area of interaction. Thus, at the last meeting of the leaders of two countries, Vladimir Putin and Xi Jinping signed nearly 30 agreements in the fields of energy, aviation, space, and finance. In the joint statement of Russia and China, it states that the two countries are planning to increase investment in the field of transport, energy and infrastructure. In addition, Russia and China plan to join forces to develop a rocket engine and electronic components in the field of satellite navigation, exploring deep space. Moscow and Beijing will continue to cooperate in the field of civil aviation. In particular, the creation of wide-body long-haul aircraft and heavy helicopters was discussed. Also, the Chinese and Russian sides continue successful cooperation in the field of high technologies. It is clear that successful implementation of these agreements is not possible without the joint training of engineers; discussions, exchanges of information, views, intensification of academic exchange programs, etc. In this regard, the ATC conference may be a great opportunity for the joint discussion of Russian and Chinese issues of engineering education in the aerospace industry.

At the 2016 ATC conference, events such as the Congress of Rectors of Russian Aviation Universities, a qualifying round of the "World Skills Russia" championship, "Aviation Maintenance" and Junior skills competency "Aerospace Engineering"[1] will be held. These events are to be considered as a big step forward in the improvement of the quality of training for aviation industry and aim to encourage experts in the field of aviation education from different countries, including China, to participate in ATC.

REFERENCES

[1] 8-th International Specialized Exhibition "Aerospace technologies, modern materials and equipment Kazan 2016". http://www.aktokazan.ru/rus/ [date of application 01.06.2016].

[2] SalakhovaA.Sh.,Kozlov V.A. Method of the remote laboratory work for general technical discipline. Reports of International scientific-practical conference "Search for effective solutions in the creation and implementation of scientific developments in the Russian aviation and space industry". Kazan, 2014.

[3] SalakhovaA.Sh., EvdokimovYu.K., KirsanovA.Yu. The system of the monitoring the distant laboratory work for technical discipline. Reports of International scientific-practical conference "Search for effective solutions in the creation and implementation of scientific developments in the Russian aviation and space industry". Kazan, 2014.

[4] Dagan A.I.,Korobkova E.A., Minnikhanov R.R., Sabitov R.A., SabitovSh.R., Smirnova G.S. Integration of educational, scientific and industrial informational training and retraining environment of the engineering industry companies specialists based on modular data-centers and data storage.Reports of International scientific-practical conference "Modern technologies, materials, equipment and accelerated recovery of skilled personnel potential - a key element in the revival of national aircraft and rocket industry". Kazan, 2012.

[5] Ivanova V.N., Hnycheva D.S.Provision of enterprises of aerospace professionals of secondary vocation education using the power of the cross industry resourse center. Reports of International scientific-practical conference "Modern technologies, materials, equipment

and accelerated recovery of skilled personnel potential - a key element in the revival of national aircraft and rocket industry". Kazan, 2012.

[6] Lopatin A.A., Gopkalo A.A.The target training for industrial enterprises of Republic of Tatarstan.Reports of International scientific-practical conference "Modern technologies, materials, equipment and accelerated recovery of skilled personnel potential - a key element in the revival of national aircraft and rocketindustry". Kazan, 2012.

[7] Murtazina L.G., Avionics technician training in the field of avionics: cooperation with European aerospace clusters.Reports of International scientific-practical conference "Search for effective solutions in the creation and implementation of scientific developments in the Russian aviation and space industry". Kazan, 2014.

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TEACHING OF RUSSIAN LANGUAGE WITHIN SANDWICH PROJECT BETWEEN NAU "KHAI" (UKRAINE) AND NUAA (NANJING, CHINA)

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Key words: Sandwich project, Russian language, bachelor's degree, aerospace complexes, avionics, KhAI, NUAA.

Abstract. *This document provides information and instructions for preparing the full-length paper for the AWADE2016 Workshop (8-11 October 2016, Nanjing University of Aeronautics and Astronautics, China)*

National Aerospace University KhAI was founded in 1930 and has a long history in the development of aviation science and technology in Ukraine. Until 1991 it was a closed educational establishment which trained specialists for the aviation, space and defense industries of the Soviet Union.

KhAI is a higher education establishment training aeronautical engineers in all academic degrees and aeronautical engineering qualifications. Over the years KhAI University has trained more than 60,000 professionals who have reached high levels in professional and administrative fields. Many graduates credit KhAI as an educational institution that trains high-quality engineers with high professional and creative abilities. Many graduates have become general and chief designers, received state awards, contributed to the development of aviation and aerospace in Ukraine and around the world.

Education in KhAI has always combined with scientific research which is why a significant number of graduates have proved to be skilled researchers and contributed greatly to the development of science in Ukraine.

Achievements made in KhAI laboratories and student design bureaus having raised scholars and leaders whose names elevate Ukrainian aviation and aerospace industries, and are well known around the world.

After 1991 KhAI received the right to conduct international activities but in order to successfully implement international projects, the University had to solve a number of issues which were as follows:

1. Development of methods and experience of international activity in all forms and training of experts for its implementation.
2. Implementation of activities directed to train students and teachers in foreign languages in order to carry out international activities.
3. Development of a series of dictionaries in English and Ukrainian in aviation, space and related engineering sciences.
4. Study and practical use of international standards in aviation, space technologies and aircraft maintenance.
5. Organization of initial training for foreign students in almost all of the majors available at the University, organization of recruitment, admission, settlement and servicing of foreign citizens.
6. Organization of training for Ukrainian and foreign students in English, and provision of teaching materials and textbooks.
7. Realization of research projects proposed by academic and administrative university staff, registration and participation in international competitions for grants.
8. Implementation of advertising and marketing to ensure the competitiveness of university services on the international education market.
9. The use of modern information technologies and communication methods used by developed countries.

Throughout the years of independence of Ukraine, academic and administrative staff and students of the university have worked hard to solve these problems, most of which are settled at a sufficient scientific and practical level.

The university now carries out more than 60 international projects annually in cooperation with universities and companies, including the development of high-tech equipment and technology from developed countries around the world. KhAI is a member of International Association of Universities IAU/Unesco, European Aeronautics Science Network EASN, and an associate partner of European Group of Aeronautics and Space Universities PEGASUS.

KhAI is a powerful educational and scientific complex that has deep scientific traditions and that is well-known and recognized not only in Ukraine but in countries near and far. One of the bright examples of deep and fruitful international cooperation is the cooperation between KhAI and universities of People's Republic of China.

National Aerospace University "Kharkiv Aviation Institute", KhAI, (Ukraine) and Nanjing University of Aeronautics and Astronautics, NUAA, (China) have long-standing friendly relations. During the 1950s, KhAI specialists assisted in the establishment of Nanjing Aviation Institute (the former name of NUAA) which appeared on the basis of an Aviation College. Then there were only four faculties, and the number of students did not exceed 3000 individuals. Now it is one of the largest universities in China accounting more than twenty thousand students. In 2008, NUAA became a member of Chinese research universities.


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To whom it may concern:

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Eva Egron-Polak
Secretary-General
Executive Director

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TO

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The European Aeronautics Science Network is pleased to count the National Aerospace University "Kharkiv Aviation Institute" among its members worldwide.

Given certificate is valid during 1 calendar year.

Date:

Prof. Spiros Pantelakis
EASN Chairman

PEGASUS

Partnership of a European Group of Aeronautics and Space Universities

Involvement of National Aerospace University "KhAI", as PEGASUS Associate Partner

Prof. Gianfranco Chiocchia
Reviewer of KhAI's application

Prof. Pascal Bauer
Chairman of PEGASUS

Figure 1: KhAI is a member of IAU/Unesco, EASN, PEGASUS.

In 2007, the universities signed an agreement on the opening of a joint education program within the so-called sandwich project. Normally sandwich courses are courses offered by universities where studies take place working in industry or studying abroad. Sandwich courses normally last for four years at degree level, with work experience or foreign studies normally taking place in the third year of study. Where the candidates go and what they do depends on the subject; modern languages students might study at a foreign university, business students might work with companies abroad, while science students might work in a laboratory.

In accordance with the contract signed by NUAA and NAU "KhAI" organize joint training of bachelors and masters selected from among the students of the People's Republic of China studying majors on the list which is approved by the Cabinet of Ministers of Ukraine. Accepted students are selected by the Chinese representatives according to existing rules and regulations of China. Candidates obtain the right to study in two universities. The total training period is six and a half years. The training is planned and conducted by both universities. In the first two years, students study in China in the bachelor's degree program. Some of the academic disciplines including Russian language and specialized lectures are read by lecturers of KhaI University who come to NUAA for one term. In the following two years, students are trained in Ukraine. The Master's degree program is divided into two stages: the first lasts 1.5 years in NAU "KhAI" (within this period all requirements of the Ministry of Education of Ukraine shall be met and implemented), the second lasts 1 year in China (within this period all NUAA requirements shall be fulfilled). Students who successfully complete the training are awarded with diplomas from both universities.

Teaching of the Russian language within the project is a combination of traditional and innovative approaches to learning which takes into account the specific nature of training beyond a language environment, national, mental and psychological characteristics using basic knowledge of students in the field of language and culture, which they had acquired in their homeland. According to curriculum agreed upon by both Universities, the course of the Russian language has 128 hours of training in each semester. Despite the differences in methodological approaches, we and our Chinese colleagues have come to develop common training requirements and guidance systems. The evaluation system in China is 100 points, which we believe allows us to implement volumetric evaluation of acquired knowledge. Control in the form of written work is carried out at the end of each semester. According to each semester's results,a student either continues the course or is expelled. By the end of the program the number of students is reduced to 15-17 individuals, but those remaining are the students who can really continue their studies at our university.

Figure 2: KhAI lecturer and a group of Chinese students in NUAA.

Experience has shown that after the second semester the students have dominant receptive language skills: the ability to read and translate, answer questions on the text, and complete grammar exercises. Naturally, the training in the next phase becomes more complicated and after the third semester the student is already able to independently make their own statement on the level of micro text, using not only simple but also complex sentences. The purpose of assignments at this stage is to improve skills and abilities of situational use of language and speech patterns.

Special focus is drawn to the lessons on teaching a scientific style of speech on the basis of adapted material provided by lecturers. This is based on familiarization and consideration of the text, various types of work that are aimed at developing professional skills of speech in the field of educational and professional communication. It should be noted that some tasks cause difficulties among students, but their appropriateness is justified by the fact that teachers start to read technical lectures in Russian in the fourth semester, after which students continue their studies in Ukraine.

After the first month, when Chinese students are accustomed to the cultural aspects of living in Ukraine, it is necessary to adapt their language. From the first days of training, all students continue attending Russian language classes, but it is important that practice of communication skills take place not only in the classroom but outside of it as well. Thus the University annually organizes a conference for foreign students. The main objective of the conference is to make a report in Russian. Chinese students prepare reports under the guidance of experienced teachers-philologists. During the conference, students can practice their knowledge, report, answer questions and prepare questions for the presenters. The entire event is held in Russian.

Another important factor in the adaptation of Chinese students in Ukraine is their socialization. Events focused on such adaptation, also exist at our university. KhAI encourages Chinese students to participate in various cultural and sporting events. This facilitates their convergence with Ukrainian students, as Chinese students are able to participate actively in the life of the university, thus feel their importance.

Upon completion of training, students defend their theses and receive diplomas from both universities in bachelor's degrees. This program was titled 2+2 or sandwich program. The first graduation of Chinese bachelors was in the summer of 2011, the students majoring in “Radio Electronic Devices, Systems and Complexes”. Within this major, students study design, manufacture and operation of different electronic and radio-electronic devices, including computerized aerospace complexes (avionics), means of protection of information and objects, technical facilities of computer systems, radio-electronic household equipment.

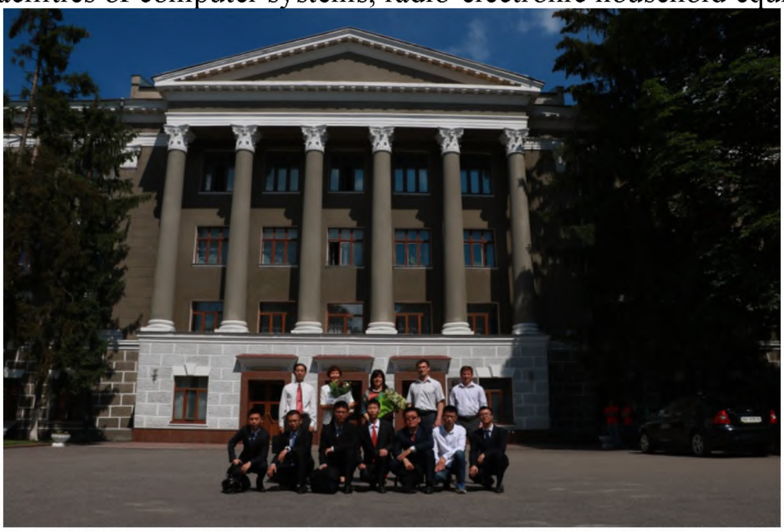

Figure 3: The sixth graduation ceremony of Bachelors (June, 2016).

Due to the success of the project the agreement was extended for the following years and in new majors. In 2015 KhAI admitted Chinese students for the Avionics major. Within this major, students learn how to design state-of-art information technologies and how to control various aerospace, power and other objects and processes as well as how to develop optimal and intelligent algorithms of control, use principles of control in technical and man-machine systems, develop architecture of computer systems and use computers to solve problems of control of objects in real time; students also learn how to create software of computer intelligent control systems by applying modern technologies of visual programming.

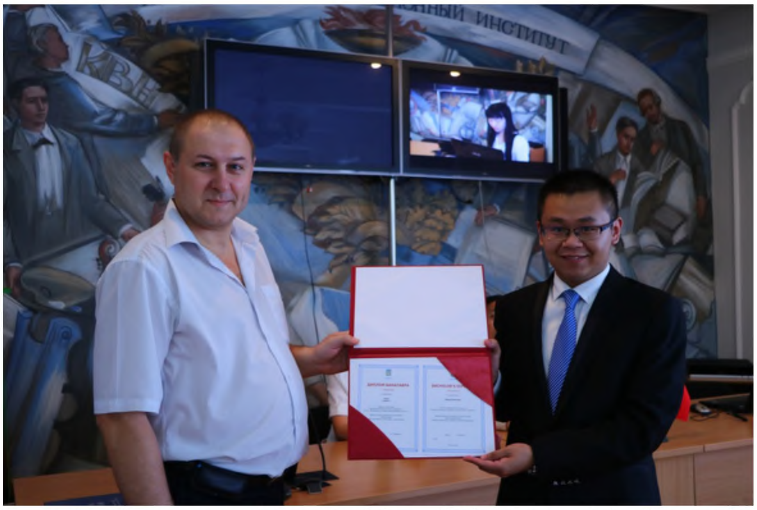

Figure 4: Chinese student - holder of diploma with distinction.

In order to facilitate the educational process, the administration of the department has made a decision to join the groups of Chinese students and Ukrainian students as previously Chinese students were trained in a separate group. This radical step turned out to be successful as Chinese students managed to master the material even faster which again proved the importance of cultural linguistic socialization along with professional training.

In conclusion, it should be noted that participation in this project is not only interesting, but rewarding as well. We are currently working on the creation of a textbook on the scientific style of speech for Chinese students who are studying within this sandwich project. We believe this would help them to deepen their knowledge even further in order to become professionals not only in their home country but all around the world.

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PROJECT "VIRTUAL INTERNATIONAL STUDENT OLYMPIAD AIRCRAFT DESIGN"

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Key words: Aircraft design, student Olympiad, video conferencing, conduct procedure

Abstract. *The article is devoted to the aircraft design competition for students with representatives and university teams, providing preparation for students studying in undergraduate and graduate courses related to the aircraft industry. This competition is proposed to be held at NUAA, using many years of experience in holding similar competitions in KNRTU-KAI. The paper deals with the basic organizational and operational points for this event, discusses the competition tasks, and the development of methods of assessing the results obtained with a view to the objective of identifying the winners.*

1 INTRODUCTION

In October 4, 1957, the people of planet Earth could see a man-made miracle that moved into space orbit and sent radio signals. It was Sputnik 1, the first man-made satellite. In 2017, we will mark 60 years of this event. In October 2017, the authors propose to organize an international student virtual contest associated with the design of aircraft in celebration of the first space flight. This event will not only reminisce about one of the greatest achievements in the history of mankind, but also will address many important educational tasks and peacemaking.

We all know that the most effective forms of studying disciplines are those that require active participation by the students.

The students are challenged to show originality by providing materials in their presentations, competitive orientation, the practical relevance of disciplines, and the extensive use of modern digital technologies.

Scientific Olympics are characterized by the listed features. On the other hand, any communication between young people, even on a virtual level, will help to push the boundaries of political stereotypes that have developed over decades. Friendship and youth contacts are a good guarantor of normal civilized relations between nations and peoples. World experience shows that the creation of high-tech projects such as reusable aerospace systems, the international space station, the A-380 and B-787 airliners, future flight projects on the Moon and Mars, and others – cannot be done without the cooperation and joint efforts of many organizations from different countries. To solve the greatest problems that mankind is facing, bright young people who have new engineering thinking are needed, so a large and friendly team of associates is required. The search for young people with the brilliant skills to participate in such projects is a challenge that must be addressed in a variety of ways, including through selection for various competitive events.

It is reasonable to believe that an effective means of attracting young people to the in-depth study any science is for them to participate in student competitions. This practice has been developed for a long time. Among the traditional, well-known and recognized international scientific olympiads are: The International Mathematical Olympiad (IMO, held since 1959), International Olympiad in physics (IPhO, held since 1967), the International Chemistry Olympiad (IChO, held since 1968), International Olympiad in Informatics (IOI, since 1989), and others. Apart from the analysis of the competition's examples, the process of preparation for the Olympics, and direct participation in them, is recognized as one of the most effective forms of training of future specialists. Many of the competitors may later become influential scientists and renowned designers. These scientific Olympics are conducted mainly in an individual science, rather than focusing on teamwork.

Competition in the field of the aircraft design does not have such a rich history. However, KNRTU-KAI has been conducting such a competition annually since 2009, and this event has shown great potential in the search for future design talent. It is no coincidence that in recent years these Olympics have been overseen directly by P. Sukhoi's Design Bureau and of Chief Designer of the fighter Su-27 Aleksey Knyshev.

In this regard, the authors of this paper suggest to organize an international student Olympiad on aircraft design in Nanjing University of Aeronautics and Astronautics (NUAA) in October 2017. To hold a traditional competition by gathering all the participants in one place is very difficult due to the high cost of transport and accommodation. However, many of the difficulties could be overcome with good preparation and by using the internet. The boundaries of an Olympiad in such format could be virtually limitless. The wide range of experience gained from holding the All-Russian Olympiads (on designing aircraft) annually (using a real participation format) in the Kazan National Research Technical University named after A.N.Tupolev (KNRTU-KAI).

2 BASIC PROVISIONS OF THE VISOAD OLYMPIAD

Virtual International Student Olympiad on Aircraft Design (VISOAD) is an individual and team competition in the field of the aircraft design using a videoconferencing format. It is to be organized for students from different countries, carried out in order to identify the most talented, capable and advanced students.

Given the methodological, political and intellectual importance of this event, the Olympiad is scheduled to be held under the auspices of the Ministry of Education of China and the Ministry of Education and Science of the Russian Federation.

Let us dwell on the key points that should form the basis of the future Regulations on holding VISOAD Olympics.

1. General questions.

1.1. The objectives of the Olympiad:

- Formation of students' deeper professional knowledge and professional competences in the field of aviation;
- The development of creativity and independent thinking;
- Identification of gifted students for the formation of personnel potential of enterprises;
- Attracting more entrants to the specialty related to the design;
- Attracting interest from companies in the process of training;
- Strengthening the links between universities and enterprises;
- Improving the quality of teaching of disciplines associated with the design;
- Improving forms of teaching;
- Establishing international cooperation at all levels (students, teachers, universities, companies);
- Reinforce the skills of the English language (for the students of non-English speaking countries);
- Instilling teamwork skills in the future graduates.

1.2. Organizing and managing the work of the Olympiad.

1.2.1. Institute of Design NUAA aircraft (Institute of Aircraft Design Technology of NUAA) is the initiator of the misuse organizer VISOAD Olympiad.

1.2.2. To organize and manage Olympics Organizing Committee formed VISOAD.

1.2.3. Organizing Committee (OC) of the Olympiad and provides training directly to its implementation.

1.2.4. Vice-Rector (Director of International Cooperation Office) heads the Olympics Organizing Committee of VISOAD.

1.2.5. The OC develops Regulations and Rules of the Olympiad.

1.2.6. The OC creates online NUAA page dedicated to the organization and holding of the Olympiad.

1.2.7. The OC sends the announcement of the Olympiad for all potential participants.

1.2.8. The OC provides an operational link with the Olympics participants, informs team leaders on all matters relating to the organization and holding of the Olympiad, it forms the basis of these tasks, prepares accounting documentation on the results of the Olympiad, posts information on the results of the Olympiad on the Internet, prepares Olympiads awards.

1.2.9. The OC members may be included employees of NUAA and other universities, representatives of enterprises and companies that contribute to the Olympiad.

1.2.10. The OC forms the jury of the Olympiad.

1.2.11. The jury of the Olympiad are to be invited, and should include well-known scientists from the field of design and designers from China and other countries.

1.2.12. The jury are to develop the challenges, including taking into account proposals received from universities whose representatives will take part in this event.

1.2.13. The jury estimates the results of the tasks of the Olympiad, ranks the results, obtains the results for the OC.

1.2.14. The OC forms a Credentials Commission (CC);

1.2.15. The CC verifies the credentials of the Olympiad participants, conducts encryption and decryptions of the authors of works, checks the conditions of the Olympiad according to develop Provisions.

1.2.16. The AC forms the Appeals Commission (AC).

1.2.17. The AC decides all disputes that may arise as a result of work on the part of members of the jury. The Commission's decision will be final.

1.3. Participation in the competition.

1.3.1. Students studying in areas of training undergraduate and graduate programs related to the aircraft industry can take part in this competition.

1.3.2. Participants are admitted to the Olympiad in accordance with the University application submitted to the Organizing Committee in the period, according to the Rules.

1.3.3. Any university in the world, dealing with training in areas of aviation, may enter only one team.

1.3.4. The application shall include the team leader from among the teaching staff, through which there is an interaction with the organizing committee, and a list of commands with the composition up to 4 people.

1.3.5. Given that the competition can participate many different countries, and given the lack of uniform requirements and common educational standards, the Organizing Committee offers universities and other parties to submit questions in the following sections of the Olympics:

– Aerodynamics and flight dynamics of the aircraft;
– The strength of the aircraft;
– Technology of production of aircraft;
– Construction and design of aircraft.

1.3.6. On the day of registration, the CC shall issue to each registered participant and each team identification number to ensure confidentiality in the process of checking and summarizing the competition.

2. The procedure for the Olympiad.

2.1. General provisions

2.1.1. Official language of communication - English.

2.1.2. The competition is held in the form of an online videoconference. During the whole time of the competition, each team should be in an office at the university equipped for videoconferences. Jury members monitor the work of each team in the online mode of NUAA.

2.1.3. The Olympiad is held according to the received rules in individual and team competition with evaluation of the results in three categories:

–" The Best Project of Flight Vehicle";
–" Best Team";
–"The Best Participant".

2.1.4. The Olympiad is held in the terms stipulated regulations, and relevant orders Confirmed.
2.1.5. Team members during the Competition may use any source of information. It is necessary to give a link to each source used.

2.2. The content of the competition days.
The Olympiad is held on the circuit shown in Fig. 1.

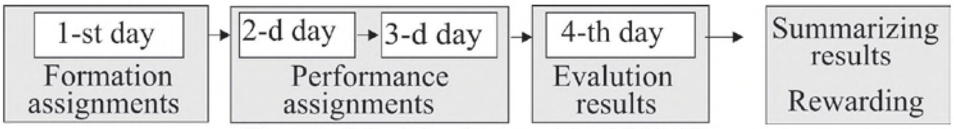

Figure1: Schedule of competition VISOAD

2.2.1. Day 1 (NUAA) - Jury develops practical task for the competition for the "The Best Project"
Sample task for practical competition.
At the level of the technical proposal to develop a conceptual design for an unmanned aircraft for remote sensing of the northern sea routes on the track motion convoys in the area of the Arctic Ocean. Specifications: weight target load - kg; range - km; speed - m / s. Special requirements: to provide for the possibility of launching from ships and landing on a ship, trapped in a net system.
2.2.2. Day 2 (NUAA) - CC sends the task of the contest "Best LA Project" team leaders who have passed electronic registration.
2.2.3. Day 2 (universities) - the team are to commence competition for the "Best Project" in accordance with the Regulations. At the end of the time allotted for the contest, teams send their work performed in the address of the Credentials Committee.2.2.4. Day 2 (NUAA) - Credentials Committee, having performed works and encrypting the sender transmits materials of the Jury, which proceeds to an analysis of solutions.
2.2.5. Day 2 (NUAA) - The jury will be preparing competitive tasks for the individual competition of the theoretical "best party" on the individual sections of design:
– Aerodynamics and flight dynamics of the aircraft;
– Strength;
– Production Technology;
– Construction and design.
The samples were targets for the divisions.
"Aerodynamics" section.
In the linear range of the polar angle of attack aircraft approximated dependence

$$C_{xa} = C_{xa0} + A \times C_{ya}$$

where C_{xa0}= const (subsonic flow), A = const.
Find $K_{\max}$ $C_{xa\,i}$ and $C_{xa\,i}$.

Section "Strength"
How to distribute the shear force Q_y between the walls of the wing spars between the first and second longerons? The height of the spars H_1 and H_2.

Section "Production Technology"

Features riveting and test for leaks.

The section "Construction and Design"

Design an algorithm of forming the structure that provides the perception and transmission of a given production load – Fig. 2:

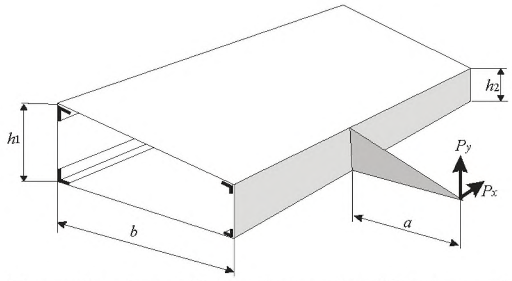

Figure 2: Example of specifying the section "Design and Engineering"

2.2.6. Day 3 - (NUAA) CC sends the task of the contest "The best participant of" team leaders, which brings information to each team member.
2.2.7. Day 3 (universities) - team members begin to carry out the competition for the "best party" in accordance with the Regulations. At the end of the time allotted for this competition, team members send their work performed to the address of the Credentials Committee.
2.2.8. Day 3 (NUAA) - CC, having performed works, reports to the Jury, which proceeds to an analysis of the presented solutions.
2.2.9. Day 4 (NUAA) - CC together with the Jury proceeds to the evaluation of the winners in the categories

–"The Best Project of Flight Vehicle";
– "Best Team";
– "The Best Participant".

3. Rules for sending jobs to university.

3.1. Prepared by the jury and approved by the OC, assignments are made in the form of a text file.

3.2. After the online broadcast, CC is satisfied that the team gathered and stored in a room designated for the Olympic Games, the team members have the appropriate badges, and the premises are no outsiders, it sends the heads of each team competition tasks.

3.3. After getting acquainted with the tasks of all the participants, each manager announces the start of the competition, from which the countdown begins.

4. Rules for execution of tasks and their references.

4.1. After receiving their identification numbers and files with job conditions, contestants perform them within the allotted time, the Regulations of the Olympiad.

4.2. Any response must contain the reasoning and decision algorithm, without which the final result of the decision of the Jury is not considering setting.

4.3. When assignments are allowed to use reference books and software products.

4.4. Decorated solutions jobs before the time the tour is sent to the representative of the CC, which transmits them to the jury for evaluation.

5. Evaluation of the results and conclusions.

5.1. General provisions.

5.1.1. Every contest section (problem, issue), the jury assigns a maximum score Mi, in accordance with the level of complexity.

5.1.2. Evaluation of the *i*-th response *j*-th participant/team carried out according to the formula

$$S_{ji}=k_jM_i,$$

where S_{ji} is the number of points earned by the participant on the task *i*; M_i is the highest possible score for the *i*-th task; k_j is the coefficient of completeness of response, which is defined by the jury for the following reasons:

k = 1.0 – absolutely correct and fully reasoned response;

k = (0.8÷0.9) – the right, but not reasoned response;

k = (0.6÷0.7) – correct, but little reasoned response;

k = (0.5÷0.6) – the answer is correct, but without sufficient justification;

k = (0.4÷0.5) – incomplete answer;

k = (0.2÷0.3) – response errors;

k = (0.2÷0.1) – wrong answer, but the right move solutions;

k = 0 – absolutely wrong response or lack of response.

5.2. Evaluation of results of competition on the "Best Project".

Project evaluation is performed for each of the sections of the formula

$$S^{P}_{ji}=k_{ji}M_i$$

where *j* is command number; *i* is number of section of the project, *i* = 1, 2, .., *N*. We propose content of the project to consider five sections (N = 5):

i = 1 – the general concept of the aircraft;

i = 2 – aerodynamics and flight dynamics of the aircraft;

i = 3 – the strength of the aircraft;

i = 4 – production technology;

i = 5 – construction and design of FV.

The overall assessment of the project of the *j*- th team S^{P}_{j} is determined by summing the results for each section of the project

$$S^{P}_{j}=\Sigma_i S^{P}_{ji}$$

5.3. Evaluation of the results of the contest the " Best Participant".

Overall estimation S^{I}_{j} determined by summing the results of each participant, on all dialed 4th divisions of competition: aerodynamics and flight dynamics of the aircraft; FV strength; production technology; construction and design of FV

$$S^{I}_{j}=\Sigma_i S^{I}_{ji}$$

5.4. Evaluation of the results of the contest "The Best Team".

In calculating this competition assessment S^{T}_{j} account the results of the first team competition and added to them the results of the three best participants of team scored in the individual competition

$$S^{T}_{j} = S^{P}_{j} + \Sigma_k S^{I}_{jk} \ .$$

5.5. After checking the jury sends the results to the CC, which carries the decoding of the authors of all works.

5.6. Preliminary results are brought together representatives of the OC and the jury in the allotted time limits.

6. Completion of the Olympics.

6.1. According to the results of the Olympic Games are determined winners in three categories.

- 3 prizes for "The Best Project";
- 3 prizes in the competition - "The Best Participant";
- 3 prizes in the competition - "The Best Team".

6.2. The organizing committee is preparing a report that exposes the results of the Olympiad on the site and sends the information to all the participants.

6.3. In case of disagreement with the results of the Olympiad participants estimate they may appeal to the Appeals Committee after the announcement of the results. Commission working time is determined by the Rules of the Olympiad.

6.4. After the approval of the results of the Olympic Games its winners are awarded with diplomas and prizes.

4 CONCLUSION

1. The proposed methodology of the Olympic Games can be adjusted and supplemented taking into account the specificity of each participating university Olympiad.
2. Of great importance to ensure the required level of the Olympiad will be attended by companies and firms associated with the design and production of the aircraft.
3. After the Olympics on its results it is recommended to conduct a methodical seminar on which a detailed analysis of the results achieved will be made, and made relevant amendments.
4. This method with the corresponding corrections can be used for the competition in other areas of study.

REFERENCES

[1] Selected papers of the International Conference joint with the XXVII International Olympiad in Informatics. Almaty, Volume 9. Kazakhstan, 2015.

[2] Goldfarb V., Krylov E., Elenskii A.. The First Student International Olympiad on Mechanism. Journal of Mechanics Engineering and Automation 3, 152-158, 2013.

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AIRCRAFT DESIGN: REAL LIFE EXAMPLES IN EDUCATION

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Key words: Aircraft design, teaching methodology, analysis, interesting examples

Abstract.*This paper deals with methods of teaching aircraft design based on the extensive use of actual case studies to contribute to the consolidation of course material and increasestudent interest and participation.*

1 INTRODUCTION

The course Aircraft Design for students enrolled in Aeronautics is certainly one of the most basic but italso quite difficult as it usually(more-or-less) unites almost all of the disciplines which students learn in this discipline(Figure 1).

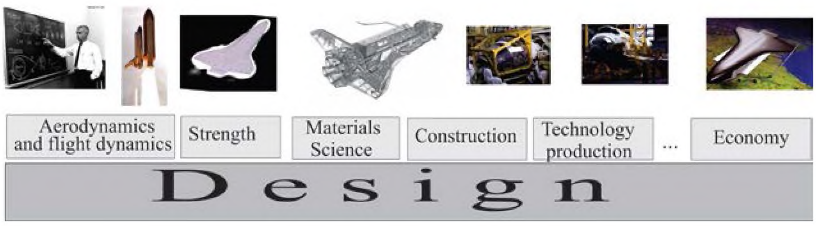


Fig.1. Components of the discipline "Design"

Given the high degree of integrality of design as an area of study, it demands the commitment of a large number of hours devoted to both the theoretical and practical aspects of the content. This commitment is often seen by many students as not allowing enough breathing room for its successful assimilation. In this regard, the teacher has to think about how to interest students so as to attract the attention of often weary young people to interact with this difficult field of study. It is no secret that every teacher believes that his discipline is the most

important, but it is the student that has the rather difficult task of equally dividing his time between all the courses that he has to undertake.
I think it fair to say that the design is not only a science but also an art.
Design, in addition to its scientific foundation, also requires that the student has some artistic abilities. Maybe that's why General Designer of the Suhkoi Bureau, Mikhail Simonov, was awarded the State Prize of the Russian Federation for technical design in the field of literature and art for the Su-27. All over the world, this aircraft is perceived as a work of art. The second prize was awarded to the Su-26 for sport and aerobatic aircraft. This aircraftis also considered an example of high art - the art of aircraft design.

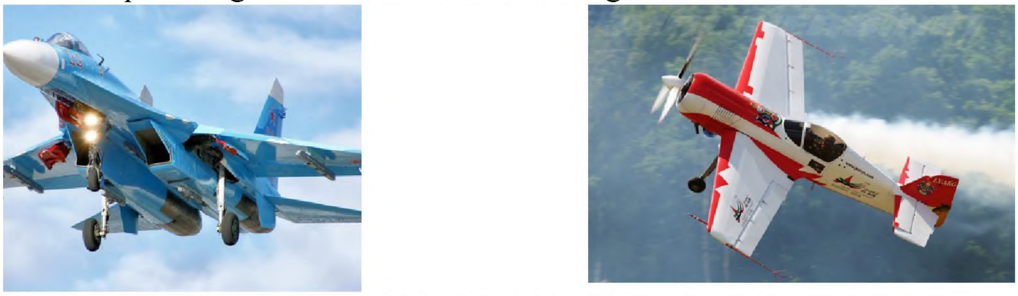


Figure 2: Beautiful Su-27 and Su-26 and fly well

A great aircraft designer said a simple but very accurate phrase about such aircraft (Fig.2) – "Only the beautiful planes fly well".

So, how do we help the students, the future designers, learn how to create beautiful airplanes?

How do we attract them to the complex, but surprisingly interesting Good fly only the beautiful planes of design? How do we encourage and foster informal learning? An essential element is the interest of the students.

One idea is for the teacher to use real-life examples during the course of teaching design to provoke interest. Often when a student begins to hear about the comic and sometimes tragic cases that occur with projects or with aircraft in service, a previously dormant interest is awakened and the students begin to show real interest, sometimes to an animated degree. There are many reasons why this happens:
Firstly, much of the subject to be covered is theoretical and of a purely scientific nature, so the application or reality of it may not necessarily be immediately obvious to the student. The teacher, more often than not, does not have enough time to cover 100 percent of the course material. The onus then, lies with the student. Since aviation has become a necessary and commonplace attribute of modern life of which most students will have taken part in, the very use of this most rapid of transport systems by the student should cause them to wonder, "what if..." This is a most interesting thing for the teacher to hear, as the student is thinking of things that they would have not previously considered, whether it is an aspect of design, operation, malfunction, or simply as in to use the equipment or vehicle as a passenger.

So, the purpose of the examples which we might use from the very beginning should make the course more attractive, interesting and informative.

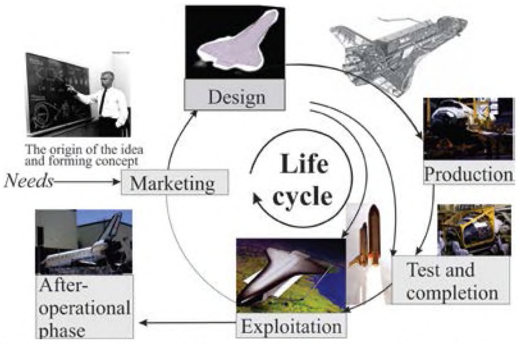


Figure 3: The life cycle of the aircraft through the creation of an aerospace plane (ASP)

Moreover, the analysis of these situations may apply to all stages of the life cycle of the aircraft: design at all stages (development requirements and the formation of technical specifications, the technical proposal, preliminary design, technical design); production; testing and refinement; exploitation; after the operational period – Fig.3

2 EXAMPLES AND ANALYSIS

Let us discuss some memorable examples that can be used in teaching the course Aircraft Design in its various sections.

Example 1. Selectingan aircraft concept.

The purpose for which a Flight Vehicle (FV) will be used largely determines its general configuration and systems. This is essentially the beginning of the project and it includes the selection and mutual spatial link parts of the whole system, its components and assemblies, their external forms and construction, design of the crew spaces, passenger and cargo areas and capacities, equipment, fuel and engines. Referring to the most expensive aircraft, which took 12 years before the first flight, which operated for 30 years and during this time continued to be refined, and then took its rightful place in the best exhibition halls. It is the reusable aerospace system, the Space Shuttle. Figure 4.

a *b*

Figure 4: Changing the concept of reusable system "Space Shuttle" in the design:
a – model at an early stage; *b* – the final version of the system

From Fig. 4, we see how dramatically the appearance of the aircraft can change during concept development. The reason in this case was the significant reduction in funding for this program. Developers analyzed hundreds of different options ranging from fully saved with LRE and SRE, with various forms of ASP wings, with the possibility of using a turbojet engine in the return phase of flight. As a result of lower funding, designers had to significantly reduce the mass of the system, so that all of the sustainer fuel for the liquid rocket engines was held in a disposable fuel tank. In the final version of the Space Shuttle, it took the form shown in Fig.4b.

Example 2. To select the FV layout.

Modern aircraft design has evolved to the point now where is a fairly stable range of possible conventional forms of aircraft, designed for a multitude of different purposes. History however, as even a brief internet search will reveal, shows many examples of aircraft design that most definitely do not fit into the conventional design basket. A brief stop to inspect some of these interesting creatures is assured to greatly enliven any audience, no matter how tired they may be.

The examples in Fig.5-6 may also contribute to the development of the students'non-standard thinking, a quality which may prove useful in creating breakthrough projects in which traditional schemes have already been proven ineffective.

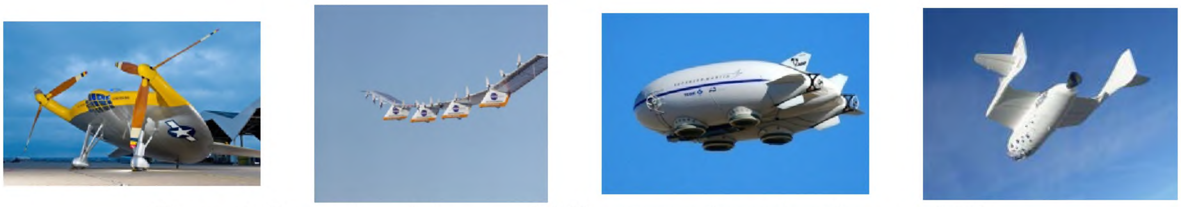


Figure 5. Examples of the use of different aerodynamic schemes of FV

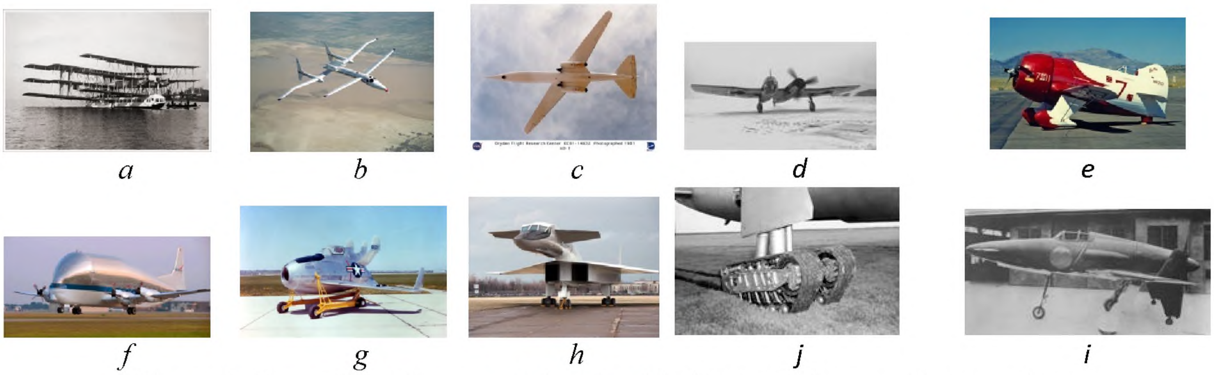


Figure 6: Examples of the use of aircraft with different schemes of: *a*–*c* – wing; *d* – *f*– fuselage; *g* – *h*– feathers; *j* - *i* – landing gear

Example 3. Atmosphere in a spaceship.

When the concept of a manned spacecraft was conceived, the most fundamentally important question to be answered was that of the atmosphere inside the spacecraft's cabin. Since neither Soviet nor American designers had any actual experience in the matter, they unsurprisingly followed different paths to solve the problem.

American ships' life support systems were calculated at 0.035 MPa pressure. In preparation for the start, and at the start of the flight, the atmosphere in the cockpit consists of 60% oxygen and 40% nitrogen, the mixture in the air vented and replaced by pure oxygen. Soviet ships were designed with an on-board atmosphere, composition and pressure close to that of the earth.

This begs the question: "which is better?"... not an easy question to answer. The American designers started from the principle of "less": on the positive side the design meant lower weights overall, but on the the negative side, the volatility of a pure oxygen environment greatly reduced fire safety. The large mass of Soviet ships reduced the fire problem in the case of a short circuit, leakage of fuel and other emergency situations that may present the possibility of a fire.

The susceptibility of the American system to the very real dangers of an on-board fire were sadly realized on January 27, 1967, when, during a ground test on board Apollo 1, a short-circuit led to an instantaneous ignition of the pure oxygen environment. Other flammable items in the crew space - nylon netting and foam pads - also quickly ignited. The entire crew: Virgil Grissom, Edward White and Roger Chaffee, trapped by a cabin door system that was difficult to operate, especially under duress, all perished in an instant. It became clear that this fundamental problem could been solved on a conceptual level, but at this stage it was too late to redesign the ship. Nevertheless, the Apollo flight program successfully completed 6 manned moon landings.

The problem emerged again on during the Apollo 13 moon mission. This expedition can be viewed in any training course as an example of the courage and heroism of the astronauts, the ground crew and the leaders of the flight, and the ability to adapt and solve intense and difficult problems under extreme duress.

On April 11, 1970, the Apollo 13 mission launched from the Kennedy Space Centre in Florida. On April 14, at a distance of approximately 330,000 km from Earth,one of three fuel cells, cryogenic oxygen tanks, in the Service Module, exploded. The subsequent failure of the remaining two fuel cells (within about 3 minutes of the initial explosion) that provided the power supply to the Command Module of the crew compartment meant that the crew had to move into the Lunar module to survive. Using the undamaged engine and the moon's gravity,the Apollo 13 crew adjusted the ships trajectory so that after the orbit of the moon, the ship successfully returned to earth.

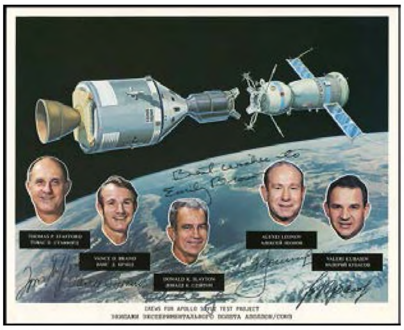


Figure 7: International space docking July 17, 1975 and their festive space dinner

Example 4: Historical docking in orbit

An interesting solution was arrived at by Soviet and American designers with the historical event of the first international ships docking in orbit, Apollo 21 and Soyuz-19 July 17, 1975 - Fig. 7. A serious problem was the different pressures within the spacecraft. To solve it, a compartment was added to Apollo where the Lunar Module would have normally been situated. After docking, the pressure in this compartment was increased to 520 mm (from 280 mm. of mercury). In the Soyuz, working pressure was reduced to 520 mm. The command module of Apollo remained at its normal level of (low) pressure but it had to be sealed for the duration of the docking with a single astronaut inside.

In terms of methodology, it is an interesting task for practical lessons about design, when students are invited to solve a particular problem, followed by an analysis of the advantages and disadvantages of each of the proposed options. For example, when analyzing the weight of spacecraft structures, one method would be to investigate the advantages and disadvantages of the reduced structural mass allowed by decreasing the internal pressure, as opposed to the effects of the increased structural mass required to accommodate the higher internal pressures of an earth-like atmosphere.

Example 5. rescue crews in emergency situations

To create plenty of student interest when studying military aircraft, the analysis of the issue of emergency crew evacuation will generate a lot of spectacular images. There are numerous positive examples that one could use, as well as some controversial ones which may cause the student to reflect somewhat longer.

One such example is the crew emergency evacuation system for the Tupolev Tu-22 supersonic bomber (Figure 8).

Figure 8: The Tu-22 and its ejection seats

In a complete reversal of conventional thinking, the three ejectionseats of the Tu-22are fired downwards. This creates severe height restrictions when ejecting from the aircraft. Crew ejection can only be attemptedabove 230-245m in horizontal flight, and 340m in the planning with the engine off. For emergency evacuation from the airplane after a belly landing or other emergencies that might occur on the ground, the crew of three would have to use the top hatches. As they say “The rescue of drowning is the handiwork of drowning”.

Figure 9: Aircraft created in Tupolev's Design Bureaus

Unusual ejection procedures aside, overall the Tu-22 was not considered a success. The aircraft was very difficult to fly, had uncomfortable seats, a much higher landing speed than previous aircraft, and very poor all-round visibility that significantly impeded the pilots' ability, particularly during takeoff and landing. The plane did not forgive the slightest error of pilots. Pilots nicknamed the plane "awl", which indicated a mutual dislike between aircraft and pilot. General Designer Andrey Tupolev hadcreated more than 300 projects, most of which have been implemented (Figure 9), but he considered this aircraft one of his most unfortunate. As the saying goes, "every family has its black sheep." However, thanks to the lessons learnt from these errors,Tupolev's design Bureau were able to create such unique bombers like the Tu-22M3, Tu-160, some of the characteristics of which are still considered the benchmark for that type of aircraft.

Example 6. From ancient times to the present day

Any section of design can be made more fun and interesting by analyzing the historical development of the topic. Another example is also associated with the concept of an emergency ejection system from aircraft (Fig.10-11). After the disaster of the Challenger space shuttle, which exploded shortly after take-off with seven astronauts on board, the developers went back to looking at emergency rescue systems.The new space shuttle, Columbia, was fitted with ejection seats for two crew members, but even though the space shuttle system has been retired, the question of how to provide a conceptual solution to the problem of safely leaving the reusable spacecraft in the case of emergency situation at all altitudes and speeds remains a viable challenge for future designers. (Figure 12) This issue still requires careful consideration and you can offer students a wide field of creativity for their unblinkered consciousness to come up with answers.

Figure 10: First rescue system for balloonist

Figure 11: Detachable cockpit F-111

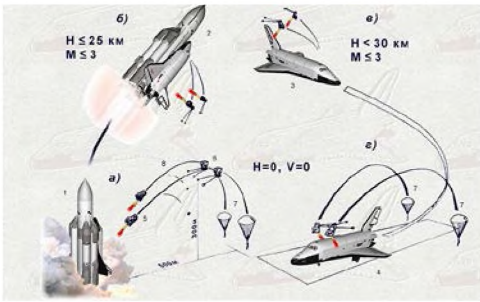


Figure 12. Astronauts Rescue System on the shuttle "Buran"

Analysis of aircraft accidents clearly shows that most of the problems come down to human error. Most often, these incidents are attributable to failures in communication. Miscommunication is the leading factor in over 70% of runway incursion incidents: pilots, controllers, maintenance staff and the like moving around airports, must use radios and other electronic devices to communicate, and mishearing or misunderstanding directives or messages can lead to disaster.

An example of such a fatal mistake – the largest aviation disaster in the world, occurred at Teneriffe in the Canary Islands in 1977. A collision between two Boeing 747s, KLM 4805 which was taking off, and Pan-Am 1736 that was taxiing toward him on the runway,killed 583 people. The runway was shrouded in thick fog and the taxiways were clogged with parked aircraft that had been diverted there due to a bomb explosion at their destination, the nearby Las Palmas airport. The KLM Captain made the disasterously mistaken assumptions that the runway was clear and that they were cleared to take off. Neither assumption was correct and the KLM 747 struck the Pan Am jet at approximately 260kmh, resulting in everybody on KLM being killed, with 61 survivors from the Pan Am aircraft.

It was this single disastrous accident that reinforced the reality that pilots and controllers rely almost exclusively on voice communications, and that effective verbal communication is essential for ensuring safety in civil aviation. As a result, a standardized phraseology for aviation has been developed, focusing on an absence of grammar, complexity and ambiguity, and consisting of simple, clear messages that are sufficient to communicate 95% of what pilots and controllers need to say to each other.

Human error can also be a factor in areas where the aircraft has suffered some kind of failure of its systems or structure. Graduating students are often lead to find work at airports, being involved in repair or maintenance. Both of these areas are vital in maintaining the reliability and integrity of the original design.

To use another tragic example, I draw your attention to the 1985 crash of a Japan Airlines Boeing 747. Due to a poor quality repair from a tail-strike incident during landing some 7 years earlier, the aircraft suffered a major structural failure in flight, and the resulting crash claimed the lives of all but 4 of the 524 people on board. It would seem that in such situations, the designer is helpless, as not only were correct procedures to effect the repair not followed, but the inspection of the repair work did not reveal the improper repair, and the aircraft was put back into service.

However, to reduce the risk of possible structural failure, it is no coincidence that experienced designers always considered various kinds of non-standard situations to ensure their designs are foolproof. Before the widespread advent of computers, designers were forced to be more sensitive to the practical aspects of construction and maintenance. Now, a fair greater amount of time is dedicated to analyzing results of design arrived at by computer modelling. Sometimes, this has had the opposite effect of actually making the design process more complicated rather than making it easier.

However, as in the past (in the pre-computer era), much depends on a confluence of circumstances, as is often said, "from the fate."

Which brings us to our next example:

Example 7.Freezing o-ring seals: the Challenger catastrophe

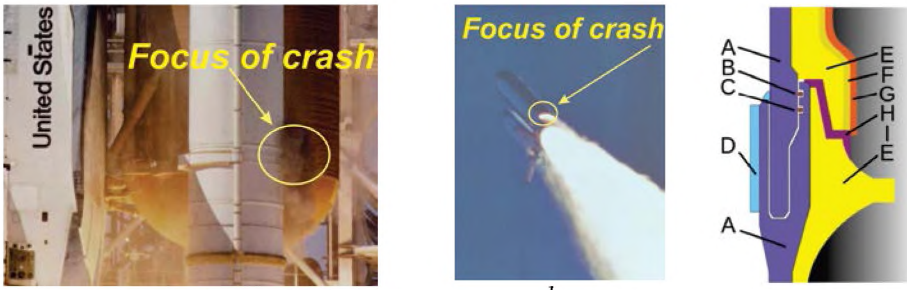
On the morning of 28th January, 1986, temperatures at the Kennedy Space Centre at Cape Canaveral, Florida, had dropped below freezing. At 11:38am that morning, after a six day delay due to weather and technical problems, the 25th space shuttle mission was launched. The launch had attracted more media attention than usual, as it was carrying the first school teacher to go into space. Christa McAuliffe was planning to give lessons to children in schools throughout the US while she was in orbit.

Earlier, engineers had warned their superiors thatthe rubber O-rings that sealed the joints of the shuttle's solid rocket boosters were vulnerable to failure at low temperatures. However, these warnings went unheeded, and Challenger lifted off. 73 seconds into the flight, amid great columns of smoke and fire, Challenger broke apart before the disbelieving eyes of the hundreds of onlookers (including the families of the crew) who had gathered to watch the launch, as well as the millions watching on live television, and plunged into the ocean. All seven astronauts on board had perished in an instant.

The destruction of the aircraft was caused by damage to the sealing ring on the right solid rocket booster. The resultant hole in the side of the booster, and a powerful jet stream in the direction of the external fuel tank destroyed the tail mount of right solid rocket booster and the load-carrying structures of the external fuel tank. Elements of the complex began to move relative to each other. This was followed by the destruction of the external fuel tank and the detonation of the fuel components.

At the conclusion of the commission of inquiry into the disaster, it was found that NASA managers had not paid enough attention to the potentially dangerous effects of the failure of the sealing rings. They also ignored warnings about the dangers of launching the ship during periods of very low temperatures, as were experienced on the morning of the launch.

The commission also found that Morton Thiokol, the company that designed the solid rocket boosters, had ignored warnings about potential issues, and that NASA managers were aware of these design problems but also failed to take action.



Legends: A - steel wall 0.5 inches (12.7 mm) thick
B - base O-ring gasket,
C - backup O-ring gasket,
D-Strengthening-Cover band, E - insulation,
F - insulation,
G - carpeting,
H - sealing paste,
I - fixed propellant

a *b* *c*

Fig. 13. The Challenger disaster: *a* - the appearance of smoke in the compound of the lateral sections of the booster on launch; *b* - burn-wall accelerator; *c*– simplified cross section of the joints between rocket sections.

(*photosfrom Wikipedia*)

Thus the root cause of the problem that precipitated this whole tragic chain of events lies in the fact that the designers designed a poor system to connect the different sections of the solid booster.

Example 8.Thermal protection concepts

The second Space Shuttle disaster almost forced the premature closure of the entire Space Shuttle program. The main culprit for this tragedy was the unreliable operation of the Thermal Protection System (TPS) of the spacecraft during re-entry.

On 1 February 2003, shortly before the successful completion of the 107th Space Shuttle mission, air-spacecraft Columbia, carrying seven astronauts, disintegrated during re-entry to the earth's atmosphere. The main parts of Columbia's TPS consisted of tiles of thermal insulation foam made from ceramic fibersable to withstand temperatures of up to 1250°C, and carbon-carbon panels on the leading edge of the wing, rated to withstand temperatures of up to 1650°C. The lower boundary of this corridor is associated with two restrictions: strength restriction defined by the maximum normal overload$n_y \leq 2.5$ and thermal restriction connected with the maximal temperature of the vehicle surface $T_{max} \leq 1650$°C (Fig.14, *a*).

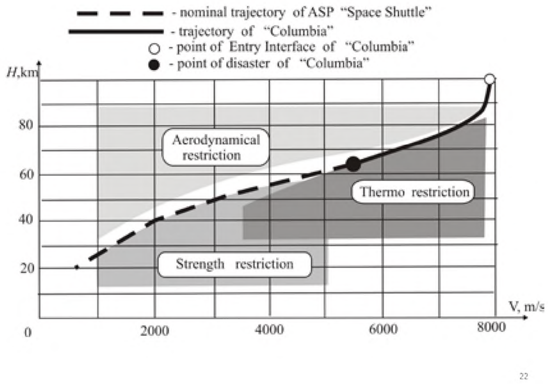
According to official report, a flow of hotgas of several thousand degrees forced its way through a damaged thermal insulation tile on the leading edge of the left wing and into the wing structure.The load-bearing structure of the wing sections were made of aluminum alloys which, without insulation, would start to lose their load-bearing capabilities at 300°C, and at 650°C, would start to melt and disintegrate. Mission control noticed abnormally high temperatures coming from sensors in the left wing, and then increasing tire pressures in the landing gear, followed by the loss of the sensors.

With a temperature now several times that of which it could withstand, the wing structure began to break up and then separate from the ship, resulting in Columbia rolling and bucking out of control. Evidence indicates that the crew was conscious at this point and aware of the increasing temperature and loss of control, however at an altitude of 60 km and a speed of 20,160km/h (5.6 km/s), Columbia's main cabin structure began to break apart some 40 seconds after the separation of the left wing. The immediate depressurization of the crew spaces as they broke apart meant that the crew were knocked unconscious or killed at that instant.

If we return to the launch of Columbia's final mission on 16th January 2003 (Fig.14, *b*), it was found that at an altitude of 20-km, a piece of insulation 0.5x0.375x0.125 m was shed from the pylon of the external fuel tank of the Shuttle, which at this stage of the flight was moving at 785 m/s. The piece was entrained by the streamlining flow and reached acceleration of 10g relative to the Shuttle. Having passed almost a half of the spacecraft's length and having attained the speed of about 220 m/s, the foam hit the left wing's leading edge and crumbled to pieces.

This process was simulated in the laboratory afterwards using a gas gun, and the results shocked everybody. A large hole was punched in the carbon thermal insulation of the horseshoe-shaped leading edge of the wing. It is impossible to reproduce a real flight inlaboratory environment, but all the same one can not get rid of the feeling that experimenters had overdone it.

This disaster can be used to deal with different perspectives: reliability, durability, heat transfer, and overall design. However, the question as to the ideal thermal protection systemremains.



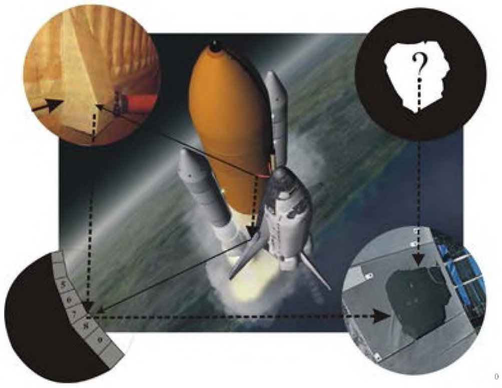


Figure 14: The Columbia disaster: *a* – trajectory of re-entry of orbiter;
b – chain of events that disrupted the thermal protection system

It is unacceptable responsible places design errors. It is no accident the safety factor increases for them. But, as experience shows, the error is almost always inevitable. The question is how to be on time to find and fix.

In some cases, the absolute best design errors are invisible and can be shown not at once, or only when a particular set of circumstances.

Example 9. Fatigue design.

In 1972, an Antonov An-10 carrying 122 people, began its approach to land at Kharkov airport, Ukraine.At an altitude of 1700 meters, the ship suddenly began to crumble apart.

The investigation showed that the cause of the disaster was a massive structural failure of the center wing section due to a fatigue crack in the lower central wing panel. The crack began to grow rapidly in both sides of the panel and then moved to longerons. As a result, both wings separated from the fuselage causing the fuselage to crash into a wooded area below.

The An-10 was designed for general technical resource of 20,000 flight hours and 12,000 cycles. At the time of the incident the aircraft had been in operation for 11 years, and had flown about 15,500 hours, completing more than 11,000 cycles. Following this accident, an investigation revealed fatigue cracking of the wing centre-section stringers on many of the remaining An-10s in service. The operator of the aircraft, Aeroflot, withdrew the An-10 from passenger services. 25 an-10aircraft deemed to be in good condition were transferred to the VVS (Soviet Air Force) and other government units, but even these remaining aircraft were retired by 1974, with many examples being donated to museums, parks and several were converted into childrens' theatres.

Example 10. Wear design

The Yakolev Yak-42 is a three-engined, low-wing, all-metal monoplane with a design lifespan of 30,000 one-hour flights. With a passenger capacity of around 100+ people, it was designed as a short-medium haul airliner which came into service at the end of 1980. Not unusually for aircraft with rear-fuselage mounted engines, the Yak-42 featured a T-tail, an emmpennage configuration where the tailplane is mounted on top of the vertical stabiliser.

In 1982, an Aeroflot Yak-42 crashed in Belarus, killing all 132 people on board. The cause was found to be a failure of the aircraft's jackscrew mechanism from metal fatigue which resulted from flaws in the Yak-42's design. The failure of the mechanism and resulting loss of control put the aircraft into a steep dive thus exeeding the aircraft's design loads, at which point it began to break up mid-air. The accident aircraft had only been in service for less than a year, with approximately 800 hours total flying time. As a consequence, all Yak-42's were temporarily withdrawn from service until the design defect was fixed, returning into service some 2 years later.

This crash has haunting similarities to the crash of another T-tail aircraft in 2000, the McDonnell Douglas MD80, flown by Alaska Airlines. Once again, the jackscrew failed and sent the aircraft into a steep dive. Initially the pilots were able to regain control and make plans for an emergency landing. However, shortly after stabilising the aircraft, the jackscrew failed completely. The pilots were unable to control the aircraft, and it dived inverted into the Pacific Ocean, killing all 88 on board.

In both cases, the design and maintenance of the jackscrew and acme nut assembly were found to be at fault. In the Alaska Air case, an Alaska Air mechanic had recommended in 1997, 3 years prior, that the jackscrew mechanism in the accident aircraft be replaced due to it showing excessive wear. This recommendation was ignored and the aircraft continued in service, and the inadequate maintenance procedures followed by the airline continued until uncovered by the resultant investigation.

Figure 14: Aircraft An-10 and Yak-42 with a difficult life

3 CONCLUSION

We could continue to recount similar examples almost indefinitely, all of which can be useful in varying degrees, to those who seek to study the art and discipline of design, and to those who want to create systems, be they simple or complex, and make them as safe and as effective as possible.

Communicating with students who have graduated from university more than 30 years ago, many say that such examples still remain in their memory and are still a good guide for for them as they progress through a career in design.

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LEARNING OF RUSSIAN AVIATION REGULATIONS BY CHINESE AND INTERNATIONAL STUDENTS

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Key words: Russian Aviation Regulations, Russian Federal Aviation Regulations, airworthiness substantiation, airworthiness management, educational process in China.

Abstract. *Chinese Aerospace Engineering is currently in a phase of rapid development which puts the highest demand for highly skilled professional engineers. In particular, the current cooperation with Russia has revealed the need of tailoring the Chinese educational process to better understanding of Russian airworthiness management system. The paper describes typical difficulties faced by Chinese and International students throughout their learning of Russian regulations. They have been found to be: two general types of regulations used in Russia, many separate agencies responsible for aircraft airworthiness management instead of one national aviation authority, and continuing reorganization attempts, not harmonized structure of some Russian aviation regulations as compared to other unified regulations, intersections in effectiveness, wider range of certificates issued, very different Aircraft Operation management system, language barrier in explanatory materials and websites. The paper also briefly introduces typical tasks and ways of Chinese educational system improvement and its pointing towards better command of the topic.*

In the past, China was just an operator of aircraft purchased from overseas. But lately, China has become one of a group of countries which are able to design and manufacture their own aircraft from the very beginning of the process to its final stage. At this point in time, COMAC Aircraft Company (中国商用飞机有限责任公司) has already developed ARJ21 and C919 airplanes. Currently, their work has been extended to a new long range wide-body commercial airplane (C929/ C939) in cooperation with Russia.

This should be taken into account for further improvement of educational background of Chinese students and for raising the professional skill of aircraft company staff. Now, not just aircraft airworthiness maintenance management is important for their education but also the entire aircraft development process along with aircraft airworthiness substantiation. An airplane cannot enter service unless a manufacturer has demonstrated that an airplane complies with applicable airworthiness regulations and a national aviation authority agrees that they've been met.

As the development process involves Russia as a foreign country, Russian airworthiness regulations have to be additionally taken into consideration. This is the reason why new courses on Russian regulations have been introduced to Chinese college students and to visiting professionals from Shanghai department of COMAC Aircraft Company. However, the methodology of teaching and working with Russian regulations is different for Chinese students due to their dissimilarity from well-studied Chinese Civil Aviation Regulations (CCAR) and worldwide known Federal Aviation Regulations (FAR) of the U.S.A. or Certification Specifications (CS) of the European Union.

Russian regulations include (1) Aviation Regulations (AP; Russian: Авиационные Правила, transliteration: Aviatsionnye Pravila) [1] issued by the Interstate Aviation Committee and being effective in all member countries of the interstate treaty. (2) Numerous Orders of different Russian ministries and agencies united into a set of documents named Federal Aviation Regulations (FAP; Russian: Федеральные Авиационные Правила, transliteration: Federal'nye Aviatsionnye Pravila) [2-8], being effective in Russia exceptionally, and mainly used for aircraft operation. Such a confusing name of Russian Federal Aviation Regulations (FAP) sounding completely identically to American Federal Aviation Regulations (FAR) has been grounded on the fact that the full name of Russia has been the Russian Federation. All Russian governmental agencies hold the Federal status, that is why the word "Federal" has also come into the name of Russian regulations. To avoid misunderstanding, the abbreviation "FAP" has been established based on the authority's name transliteration from Russian language.

The organizational structure of authorities responsible for aviation regulations is also different in Russia comprising 7 separate Agencies instead of one national aviation authority which is common in other countries. They have been:

(1) the Interstate Aviation Committee [1],

(2) the Government of the Russian Federation [2],

(3) the Ministry of Transport [3,4],

(4) the Ministry of Defense [4,5],

(5) the Russian Air Navigation Agency [6] (abolished in 2009),

(6) the Russian Aerospace Agency [4] (the present name is the Roscosmos State Corporation for Space Activities, Russian: Роскосмос, transliteration: Roscosmos, English: Russian cosmos),

(7) and the Federal Aviation Service [7], later in 1999 renamed to Federal Air Transport Service [8] (the present name is the Federal Air Transport Agency (Rosaviatsiya), subordinate to the Ministry of Transport, Russian: Росавиация, transliteration: Rosaviatsiya, English: Russian aviation).

In November 2015, it was announced and the certain governmental order [9] had been signed that the Russian Airworthiness management system would be reorganized, responsibilities would be redistributed among only 3 agencies involving more new names to the list:

(1) the later known Ministry of Transport

(2) and the Federal Air Transport Agency (Rosaviatsiya), subordinate to the Ministry of Transport,

(3) and a new name of the Ministry of Industry and Trade.

The learning of the regulation management system by Chinese and International students has been found to have certain difficulties as regulation content is arranged into parts differently from Chinese regulations which have been harmonized with the worldwide commonly used structure of regulations. It's worth noting that Aviation Regulations (AP) do not have as many parts as American FAR regulations do. However, they follow the typical content structure of American FAR regulations which has been an outcome of a continuous harmonization process started in 1990s by the Interstate Aviation Committee [10]. Meanwhile, Russian Federal Aviation Regulations (FAP) have been issued with absolutely own structure which is assumed to be a result of distribution of Airworthiness management responsibilities among separate agencies. In addition, these two general types of Russian regulations both have their own limitations in use restricted to particular conditions, on one hand, and intersection in effectiveness force, on the other hand.

The kinds of certificates are of a wider variety in Russian Airworthiness system. For instance, they include such special kinds as Type Certificates for radio communication facilities, Type Certificates for meteorological equipment, Medical center Certificates, and many other titles [11] in addition to well known Type and Airworthiness Certificates.

It's worth highlighting that the Aircraft Operation management system is controlled by Russian Federal Aviation Regulations (FAP) only. The operation related documents are very different from American or European regulations as they display their own content structure [2-6,8] not following typical operation regulations like the American FAR parts 91, 121, and 135. This is why the Russian system doesn't have anything like Aircraft Evaluation Group (AEG) which has been commonly used for determination of operation and maintenance acceptability by national aviation authorities of many countries including China.

The language barrier is also experienced not only because Russian regulations along with relevant documents have always been issued in Russian language, it's obvious to any national aviation authority, but also due to a lack of explanatory materials and accurate English translation for news information on a number of official Ministry websites.

The above-mentioned key aspects are summarized in a totally different structure, and the contents and effectiveness of Russian regulations are not fully harmonized with the unified American or European Union regulations. This has created the highest concern and has been well highlighted during class teaching. The students' learning has benefited from the analytical study of a range of application and influence through part-to-part comparison of corresponding regulations in Russian and Chinese document space. The key roles of Russian ministries and agencies have also been subjected to a deep study for clearer understanding of their interaction in airworthiness matters.

REFERENCES

[1] *Авиационные Правила: АП-21. Сертификация авиационной техники, организаций разработчиков и изготовителей.* Межгосударственный Авиационный Комитет, 2013.
Aviation Regulations: AP-21. Certification procedures for Aeronautical Products, Design Organizations and Manufacturers. Interstate Aviation Committee, 2013. (in Russian)

[2] *О федеральных правилах использования воздушного пространства и федеральных авиационных правилах*: постановление Правительства Российской Федерации от 27.03.1998 №360 (ред. от 18.02.2016).
About Federal Regulations of airspace use and Federal Aviation Regulations: order of the Government of the Russian Federation from 27.03.1998 No.360 (edition from 18.02.2016). (in Russian)

[3] *Об утверждении Федеральных авиационных правил "Подготовка и выполнение полетов в гражданской авиации Российской Федерации"*: приказ Министерства транспорта Российской Федерации от 31.07.2009 №128 (ред. от 15.06.2015).
About ratification of Federal Aviation Regulations "Flight preparation and implementation in Civil Aviation of the Russian Federation": order of the Ministry of Transport of the Russian Federation from 31.07.2009 No.128 (edition from 15.06.2015). (in Russian)

[4] *Об утверждении Федеральных авиационных правил полетов в воздушном пространстве Российской Федерации*: приказ Министерства обороны Российской Федерации №136, Министерства транспорта Российской Федерации №42, Росавиакосмоса №51 от 31.03.2002.
About ratification of Federal Aviation Regulations of flights in airspace of the Russian Federation: order of the Ministry of Defense of the Russian Federation No.136, the Ministry of Transport of the Russian Federation No.42, the Russian Aerospace Agency No.51 from 31.03.2002. (in Russian)

[5] *Об утверждении Федеральных авиационных правил производства полетов государственной авиации*: приказ Министерства обороны Российской Федерации от 24.09.2004 №275.
About ratification of Federal Aviation Regulations of Public Aviation flight implementation: order of the Ministry of Defense of the Russian Federation from 24.09.2004 No.275. (in Russian)

[6] *Об утверждении Федеральных авиационных правил "Сертификация объектов Единой системы организации воздушного движения"*: приказ Росаэронавигации от 26.11.2007 №116.

About ratification of Federal Aviation Regulations "Certification Regulations for joint facilities of air traffic implementation": order of the Russian Air Navigation Agency from 26.11.2007 No.116. (in Russian)

[7] *О введении в действие Федеральных авиационных правил "Сертификация авиационных учебных центров"*: приказ Федеральной авиационной службы России от 29.01.1999 №23.
About giving effect to Federal Aviation Regulations "Aviation training center certification": order of the Federal Aviation Service of Russia from 29.01.1999 No.23. (in Russian)

[8] *Об утверждении Федеральных авиационных правил "Сертификационные требования к организациям авиатопливообеспечения воздушных перевозок"*: приказ Федеральной службы воздушного транспорта России от 18.04.2000 №89 (ред. от 04.10.2011).
About ratification of Federal Aviation Regulations "Certification requirements to organizations of aviation fuel supply for air transportation": order of the Federal Air Transport Service of Russia from 18.04.2000 No.89 (edition from 04.10.2011). (in Russian)

[9] *Об изменении и признании утратившими силу некоторых актов Правительства Российской Федерации*: постановление Правительства Российской Федерации от 28.11.2015 №1283.
About changes and abolishment of some documents of the Government of the Russian Federation: order of the Government of the Russian Federation from 28.11.2015 No.1283. (in Russian)

[10] А.А. Красоткин. *Сертификация авиационной техники.* Москва, МАИ, 2007.
A.A. Krasotkin. *Certification of aircraft.* Moscow, MAI, 2007. (in Russian)

[11] *Interstate Aviation Committee. Certificates.* http://www.mak-iac.org

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IMPROVEMENT OF AIRCRAFT LIFT SURFACES INTEGRATED DESIGN TAKING INTO ACCOUNT INDUCTIVE DRAG

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Key words: lift surfaces, geometric parameters, aerodynamic and operation efficiency.

Abstract. *The objective of this paper is to analyze the existing method of aircraft lift surfaces integrated design, and the proposition for its improvement, taking into account the criterion of reducing induced drag, and also to implement this method into the learning process. This method can reduce the costs of design, as well as allowing the optimum wing geometry on the minimum induced drag criterion. The proposed method takes into account the traditional approach to the design of aircraft and it also allows for the deep aerodynamic requirements. Using this method will allow students to better understand the aerodynamic characteristics depending on the geometric parameters of lift surfaces.*

INTRODUCTION

Creating a transport category airplane is a very time consuming task. There are high demands on this type of airplane in relation to their efficiency, economy, durability, reliability, operability, etc.

The learning of students-designers of aircraft is based on modern principles of designing aircraft. It must take into account all engineering tendencies that occur over time in the aircraft industry.

Consider one of these designing directions.

The geometric parameters of the wing and tail units are determinated at start of design process in this way [1,2]: external dimensions → operation loads → inner geometric parameters → airplane weight → service life → integral efficiency indicators of the airplane (with some iterations of designing stages). It is very important to calculate the next values: area of the wing S_w, wing aspect ratio λ_w, wing swept angle χ_w, wing taper ratio η_w, area of the horizontal surface $S_{h.s}$ and area of vertical surface $S_{v.s}$, horizontal surface aerodynamic arm $L_{h.s}$ and vertical surface aerodynamic arm $L_{v.s}$, which will be near their final values and will provide successful airplane operation.

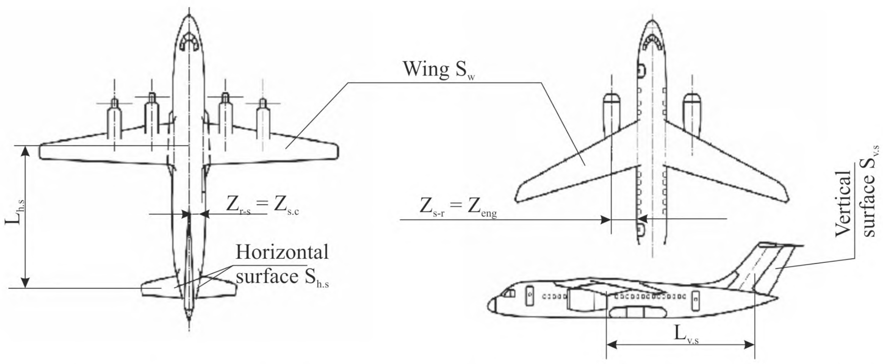

Figure 1: Base Geometric Parameters of Airplane and Geometric Relationship of Airplane Units

The important part in the tasks of the lift surfaces geometric parameters determination two factors impact:

1. World statistic data on the airplane-analogs, having been operated;
2. Own data on previous airplanes

But with this data available in traditional designing way the multi-iterative designing is obligatory: statistic preliminary geometry → checking calculations → corrected lift surfaces geometry → recalculation → new arrangement of lift surfaces.

This way of determination of the geometric parameters of wing and tail unit is not only very time-consuming and expensive, but does not exclude the mistakes in taking decisions during final design.

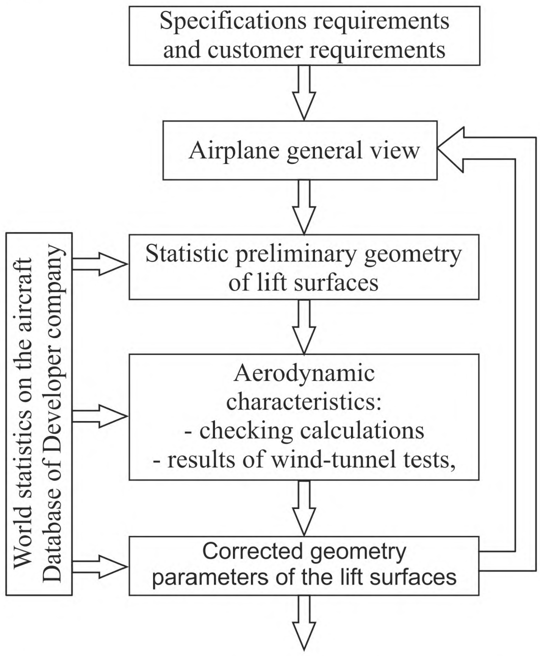

Figure 2: Layout of the Direct Task Solving on the Determination Geometric Parameters of Lift Surfaces

FORMULATION OF THE INVESTIGATION PROBLEM

A new method is proposed, one which can decrease a number of designing mistakes and time consuming problems. This method is based on the determination of geometric parameters of lift surfaces taking into account the relationship between the partial aerodynamic indicators and the integral competitiveness indicators at the preliminary designing stage. This method is also proposed for the student to understand more deeply the relationships between the external geometry of airplane and the integral competitiveness indicators.

METHOD OF SOLVING THE TASK

The layout of the method is shown in Figure 3. The scientific mean of it consists from the next fact: to solve the inverse designing task – to determine the geometric parameters of wing, such as the η, η_i, $\bar{Z}_H$, $\bar{S}_H$, $\varepsilon°(z_i)$ and tail unit as the $\bar{S}_{h.s}$, $\bar{S}_{v.s}$, $L_{h.s}$, $L_{v.s}$ by the partial aerodynamic indicators – shape ratio $K_{sh.m}$, ratio of inductive drag increment B_m, minimum possible specific tail area $\bar{S}_{t.u.\min}$ and taking into account the specific features of their arrangement.

This method does not replace the traditional method but rather, adds to it due to the determination of more rational parameters at the preliminary designing stage [1,5].

The specific features of the lift surface are specified due to the requirements of arrangement in the real structure. Due to those requirements in the real structure, additional design members are presented: break of the wing, extension of the wing, etc. Those design members influence the geometric parameters of lift surfaces, such as aspect ratio [3,4] and so on. So, it is necessary to modify them from the point of those design members.

$$K_{sh.w}(\eta_i,\ \bar{S}_{ext}, \bar{z}_{ext},\ \lambda_{ef},\ \Delta\bar{S}_{ext}, \bar{z}_{eng}, \bar{z}_{c.s}) = K_{sh.e}, \tag{1}$$

$$B_m(\eta_c,\ K_\varepsilon, \bar{\varepsilon}(z),\ \lambda_{ef},\ \Delta\bar{S}_{ext}) = B_{min} \tag{2}$$

where

$K_{sh.w}$ – real shape ratio of the wing;

$K_{sh.e}$ – shape ratio of the elliptical wing;

B_m – ratio of the inductive drag increment of the modified wing;

B_{min} – minimum possible ratio of the inductive drag increment of the wing;

η_w – taper ratio of the wing;

η_i – taper ratio of the wing section of the composite planform wing;

$\bar{z}_{ext}$ – relative coordinate of the brake of the wing spanwise;

$\bar{z}_{eng}$ – relative coordinate of the engine at the wing spanwise;

$\bar{z}_{c.s}$ – relative coordinate of the wing central section;

λ_{ef} – effective aspect ratio of the wing;

$\Delta\bar{S}_{ext}$ – extension specific area of the wing;

K_ε – general twist angle of the wing;

$\overline{\varepsilon}(z)$ – relative twist angle of the local chords by the wing span.

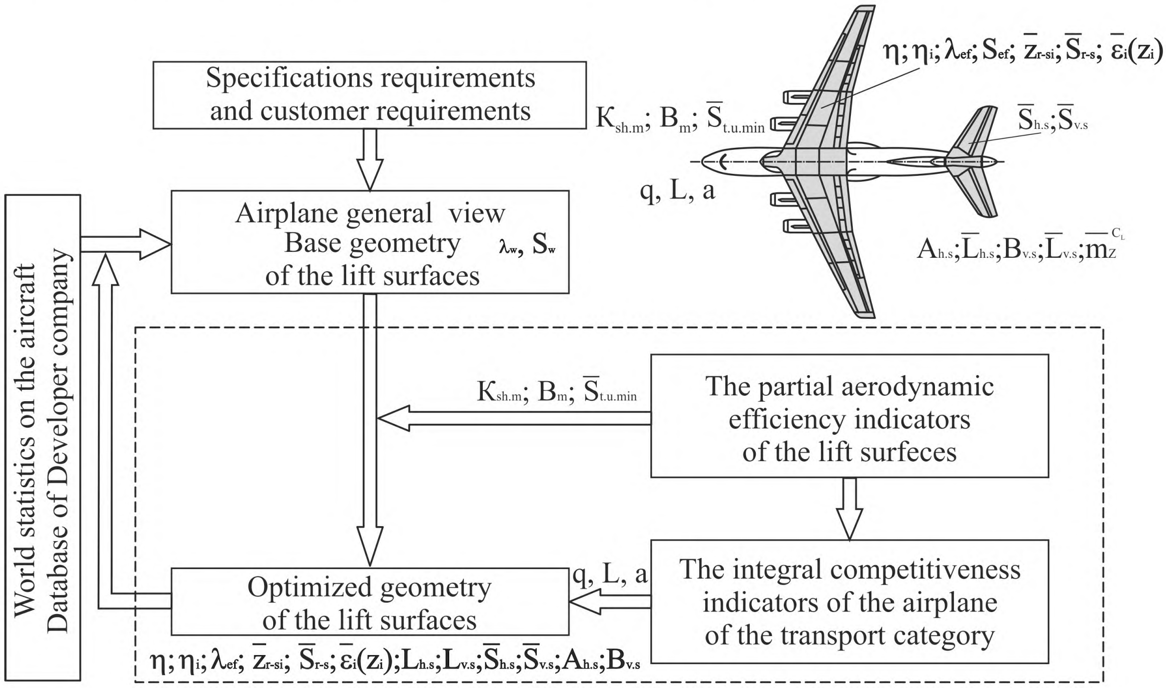

Figure 3: Layout of the Method of Solving the Inverse Task of Determination of the Geometric Parameters of the Lift Surfaces at the Preliminary Designing Stage by the Partial Aerodynamic Indicators and Integral Competitiveness Indicators

So, in the process of determination by this method, also it is necessary to take into account this next relationship: the wing influence on the tail unit and vice versa. This relationship usually is estimated by the equation [2]:

$$\overline{S}_{t.u} = \overline{S}_{h.s} + \overline{S}_{v.s} = A_{h.s}\frac{b_{m.a.c}}{L_{h.s}} + B_{v.s}\frac{L_w}{L_{v.s}} \quad (3)$$

where

$\overline{S}_{t.u}$ – specific area of the tail unit;

$\overline{S}_{h.s}, \overline{S}_{v.s}$ – specific areas of the horizontal and vertical surfaces;

$A_{h.s}, B_{v.s}$ – static moment rations;

$L_{h.s}, L_{v.s}$ – horizontal and vertical surfaces arms;

$B_{m.a.c}$, L_W – mean aerodynamic chord and wing span.

The proposed method is based on the combined solution of the equations (1), (2) and (3). The idea of their relationships is based on the geometric parameters of the lift surfaces influence to the lift-to-drag ratio, which in turn, determines the next integral competitiveness indicators: maximum flight range, fuel effectiveness, etc.

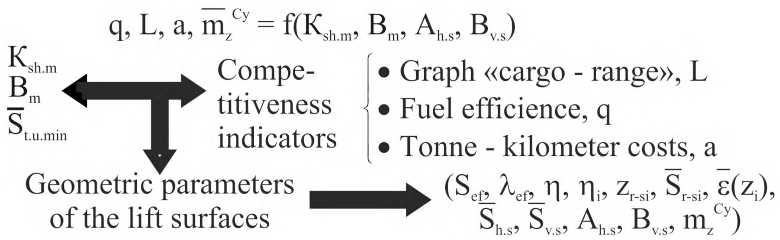

Figure 4: Layout of the Relationships between the Partial Aerodynamic Effectiveness Indicators and the Integral Competitiveness Indicators

It is possible determine the integral fuel effectiveness indicator not only by the general parameters of airplane ($m_{t.o}$, $C_{f\,cr}$, V_{cr}, n_{pas}), but by the geometric parameters of the lift surfaces (S_{ef}, η_m, η_i, λ_{ef}, $\overline{S}_{ext}$, $\overline{Z}_{ext}$, $\overline{\varepsilon}(z_i)$):

$$Q_{fuel} = f(m_{t.o}, C_{f\,cr}, V_{cr}, n_{pas}, C_L, S_{ef}, \lambda_{ef}, \eta_m, \overline{S}_{ext}, \overline{Z}_{ext.m}, \overline{\varepsilon}_m(z_i)). \quad (4)$$

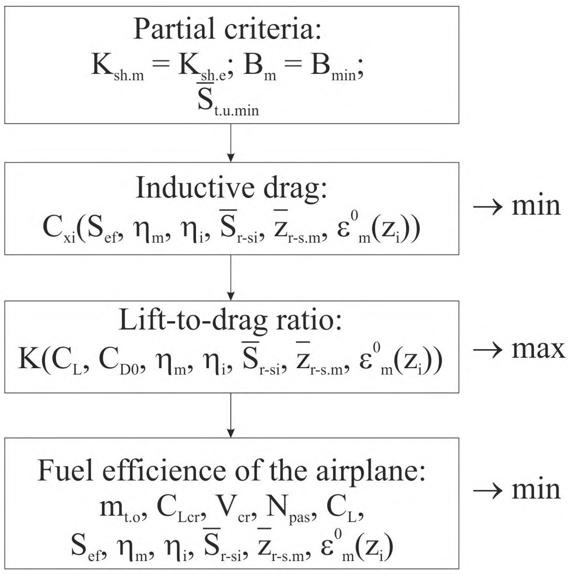

Figure 5: The Layout of Providing the Optimal Fuel Effectiveness Based on the Selection the Optimal Geometric Parameters Depending on the Partial Aerodynamic Indicators

This relationship (in full measure) demonstrates the influence of the geometric parameters complex on the fuel effectiveness indicator.

Analog relationships are set for the other integral competitiveness indicators with the partial aerodynamic indicators for transport category airplanes.

The stages of realization of this method are shown in Figure 6.

As the initial fixed parameters are taken, the calculated value of the wing area and aspect ratio are determined at the previous stage in consideration of the purpose of the airplane and the general requirements of it.

The next generation of geometric parameters of lift surfaces consists of five steps. These are parts of the scientific mean in the generation of other geometric parameters of the wing and tail unit without estimation of the weight and flight performances of airplane.

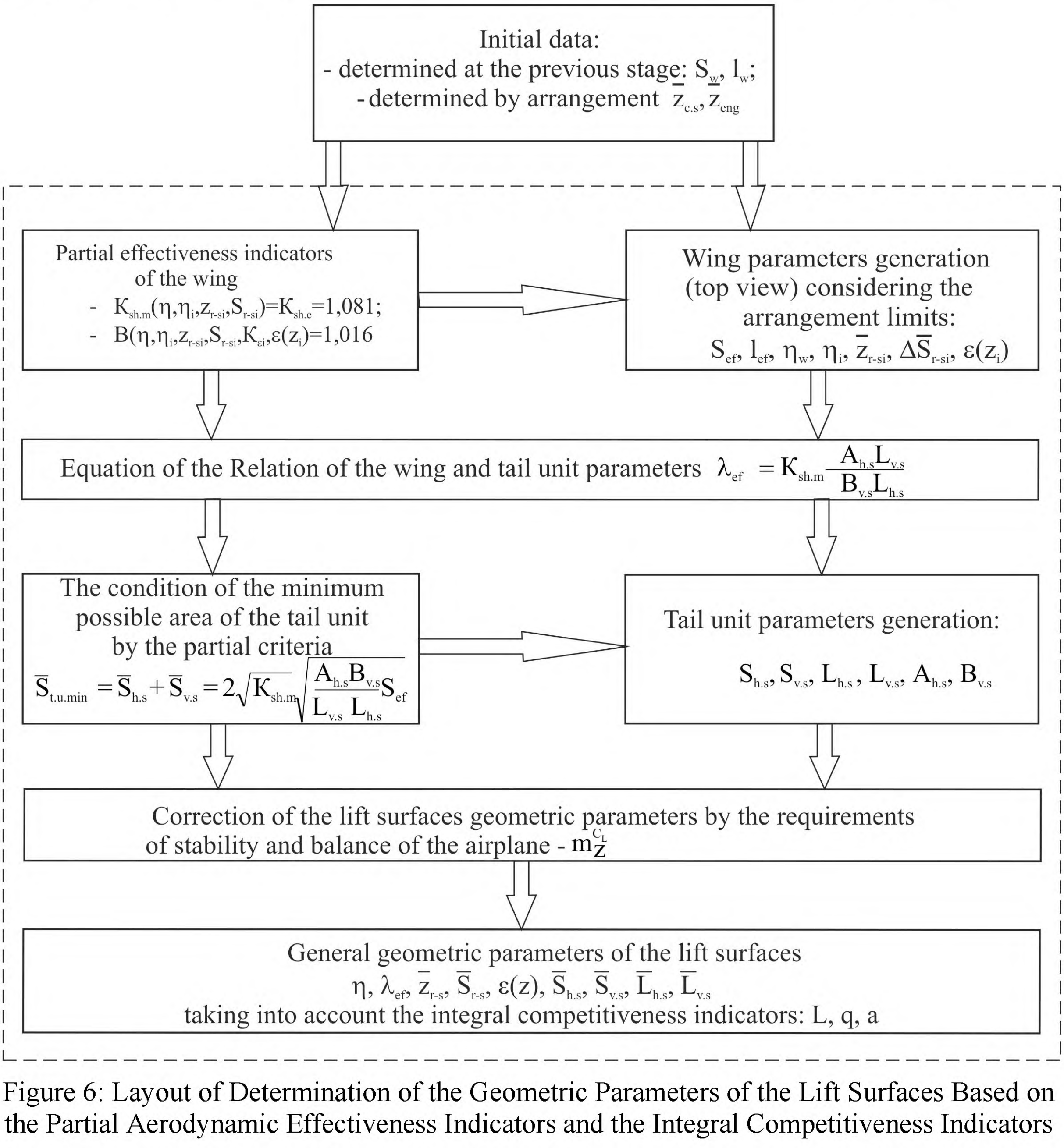

Figure 6: Layout of Determination of the Geometric Parameters of the Lift Surfaces Based on the Partial Aerodynamic Effectiveness Indicators and the Integral Competitiveness Indicators

The principal distinguishing feature of this method is that the task of generating the geometric parameters of the competitiveness partial indicators of the aircraft has not been previously considered.

So, if it is necessary to use this method in learning process, the aerodynamic and designing courses must be given at same time. The lecturer will explain more deeply the relationships between the geometry of airplane and its competitiveness indicators by using the intermediate part: the lift-to-drag ratio.

CONCLUSIONS

The method of using the aerodynamic partial indicators and the integral competitiveness indicators to solve the inverse tasks of the geometric parameters generation for the lift surfaces of transport category aircraft is proposed for the preliminary designing stage. These parameters provide the maximum possible lift-to-drag ratio and the operational indicators, and their invariability at the next design stages.

For the full realization of this method it is necessary:

– to develop this method for the determination of the aerodynamic partial indicators depending on design specific features (extension, wing break, etc.)

– to develop the complex of criteria for the determination of the lift surfaces geometric parameters depending on the lift surfaces arrangement;

– to set the interdependence of the aerodynamic partial indicators with the integral competitiveness indicators, such as the fuel efficiency and etc.

The solving of these tasks will allow realizing the main target of the new method – to generate the lift surfaces geometric parameters of airplane at the preliminary designing stage, which correspond to the optimal integral competitiveness indicators of the airplane during operation.

This also provides the student with a method to better understand the relationships between the geometry of the airplane and its flight performances.

REFERENCES

[1] P. V. Balabuev, S. A. Bychkov, A. G. Grebenikov, V. I. Ryabkov. Principles of the general designing of airplanes with the gasturbine engines. Khai, 2003.
[2] D. Kyuheman. Aerodynamic designing of airplanes. Moscow, 1983.
[3] V. V. Utenkova, V. I. Novikov, V. I. Ryabkov. The optimization method of the wing geometry by the partial criteria. Khai, Open information and computer integrated technologies scientific journal of National aerospace university 'Kharkov Aviation Institute', № 27, pp. 116-124, 2005.
[4] D. V. Tiniakov. The influence of layout limits on partial efficiency criteria of tapered wing for transport category airplanes. The Designing and Manufacturing of Aircraft National aerospace university 'Kharkov Aviation Institute', № 68, pp. 32-41, 2011.
[5] E. Karafoli. Aerodynamics of the airplane wing. Moscow, 1956.
[6] S. M. Eger, V. F. Mishin, N. K. Lisecev. Designing of airplanes. Moscow, 1983.

PRELIMINARY DESIGN OF VTOL PERSONAL FLYING MACHINE – DEREAMWINGS

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Key words: Personal flying machine, Requirements analyses, Configuration design, Sizing.

Abstract. *This paper presented a conceptual design of novel vertical takeoff personal aircraft for which requirements analysis, initial sizing, analysis of flight performance, cost and potential application prospects are provided. The flight vehicle is named DreamWings, as it is hoped that people's long-standing dream of flying freely could be realized and the wings of the flying machine are designed to meet this objective. Some common challenges in the design of such a personal aircraft were identified first with analysis on some similar concepts and technology trends. This is followed by requirements analyses, in which, the criteria of the proposed flying machine should meet are outlined. A concept configuration with rotating wing is believed to better meet these requirements. The 3D model of DreamWings was built using OpenVSP. Some preliminary calculations were carried out, along with analysis of challenges and potential solutions. Finally, this paper points out the future tasks and remaining issues for the concept.*

Nomenclature

$E_{battery}$	=	Total energy of the battery，J
E_{total}	=	Total energy required from takeoff to landing，J
E_{g1}	=	The energy required to move from the parking place to the vertical takeoff site，J
E_{vto}	=	The energy required for vertical takeoff，J
$E_{v\rightarrow h}$	=	The energy required to change from the vertical flight state to the horizontal flight state，J
E_{h}	=	Total energy required for horizontal flight，J
$E_{h\rightarrow v}$	=	The energy required to change from the horizontal flight state to the vertical flight state，J
E_{vl}	=	Total energy required for vertical landing，J
E_{g2}	=	The energy required to move from the landing site to the parking place，J
FTA	=	Number of flight-test aircraft
f_h	=	Air drag at the level flight mode，N
f_v	=	Air drag at the vertical take-off and landing mode，N

g = Acceleration of gravity，9.8m/s^2
h_{max} = Maximum altitude，m
K = Lift-to-drag ratio
L = Range，m
m_b = Battery mass，kg
m_e = Empty mass，kg
m_p = Average mass of a person，kg
m_{total} = Total mass，kg
Q = Number of aircrafts to be produced in five years
V = Maximum velocity，km/h
X = The number of passengers
ρ_b = Battery energy density，J/kg

1 INTRODUCTION

Transportation is playing a major part in modern economy and society, and commercial air transportation is providing increasing comfort for passengers and flexibility for airlines with better economics for long distance travel, in particular. However, a long standing dream of safe, flexible, and economic personal aircraft remains a technical and operational challenge, and a dream to realize. The nature of human body means that it is almost impossible to fly just with human power, development of general aviation aircraft has, to certain extent, met the demands of personal travel, but it generally requires similar facilities as commercial air transportation, albeit on a smaller scale. What is envisioned here is a concept similar to flying car model, but with vertical takeoff and landing capabilities and much improved noise and environmental footprints. Such a vehicle could be used on a daily basis by city dwellers. It could be expected that technology improvements in smart flight operations within confined air space, greener engines, better materials and more efficient aerodynamics are starting to make it a reality, in a not very far future. Such a vehicle should not exceed the size of a familiar car and therefore able to be parked on a parking slot and can take-off and land vertically without the need for a much bigger open space. The noise levels should fall within 80dB, preferable below 75dB to allow its use within cities. The biggest challenge for such vehicles is the air traffic management within city air space where traditional air traffic management technology won't work. This paper represented an early effort towards the design and eventual operation of such vehicles.

2 RELATED WORK

In 2010, NASA published the design of Puffin, a personal aircraft that uses an electric engine as a source of power, which yields minimal pollution while maintaining high-quality performance. The aircraft's range is about 80km and the maximum speed is about 240km/h. The noise is 10 times quieter than an ordinary helicopter and the seating capacity is only one person [1]. Its characteristic is that after it takes off vertically, the whole aircraft will rotate before it flies horizontally. The machine's advantage is its high speed during the level flight mode while its disadvantage is that the passenger has to maintain a prone position for a long period of time during the flight, which may affect the passenger's comfort level.

On the other hand, XTI Aircraft Company designed a personal aircraft with a seating capacity of 6 persons. Its range is about 2700km and its maximum speed is about 600km/h [2]. What makes it different is that the two ducted fans beside the wing are rotatable. Its advantages are its high seating capacity and long flying range and its disadvantage are its large parking area and relatively big drag at the vertical take-off mode.

In addition, Martin Aircraft Company designed Martin Jetpack. Its range is about 50km and its maximum speed is about 75km/h. Its seating capacity is only one person [3]. Its advantage is its small size and its disadvantage is its low speed. Another issue is that the passenger is exposed outside, which might be dangerous.

In contrast to Ehang184 produced by Ehang Company, this aircraft is completely autonomous. Its range is about 38km and its maximum speed is about 100km/h [4]. Its seating capacity is one person. The main difference between this machine and the other three examples mentioned above is its independence in control and its ability to fold for parking. However, its range and endurance time are not considered as sufficient for practical operations in addition to the difficulties for the public to accept fully autonomous mode of transportation even though it might have some advantages in terms of eliminating human errors in the operation.

In conclusion, since the research in these types of personal flying machines has just been initiated, most of the concepts still have to be manned. The size is relatively large and the cost is so high that the general public cannot afford it. In addition, the safety record remains to be proven. In the future, the personal aircraft is expected to be safer, more comfortable, more autonomous and more environmental friendly. Similar to today's private cars, it would become affordable for the public as an alternative mode of transportation, especially between neighboring cities.

3 CONCEPTUAL DESIGN OF DREAMWINGS

3.1 Design process

Top level design parameters of DreamWings were decided first after requirements analyses. This is followed by a configuration study in which multiple configuration designs were compared and analyzed. Some preliminary design on how to fold the wings and the empennage part were carried out. Calculations were done on weight, aerodynamic forces, performance, structure, cost, etc. A 3D model of DreamWings was then built using OpenVSP tool [5]. Lastly, the future tasks and remaining issues for the concept were pointed out.

3.2 Requirement analysis

Parameters	Values	Brief explanations
Maximum seating capacity	2, could be increased to 4	Ordinary private car：5

Average weight of a person (kg)	70	Average weight of adult males: 66
Total length after folding (m)	≤5.3	General parking space length：5.3
Total width after folding (m)	≤2.5	General parking space width：2.5
Total height after folding (m)	≤2.2	General underground parking lot height：2.2
Total length before folding (m)	Calculated	/
Total width before folding (m)	≤7.5	Two-way Lane width：7.5
Total height before folding (m)	Calculated	/
Fuselage width(m)	0.8-2.5	Ordinary human body width：0.52
Empty weight(kg)	350	Refer to NASA puffin:181 EHANG184:200
Maximum altitude(m)	1000	Relevant policies allow private aircraft to use airspace under 1000 meters
Maximum level flight speed(km/h)	≥300	Refer to NASA puffin:241 EHANG184:100
Maximum range(km)	300	Straight-line distance between Shanghai and Nanjing: 300 Between 3-5 hour drive car journey
Battery energy density(MJ/kg)	0.72	Lithium-ion battery：0.72

Table 1: The desired parameters of DreamWings

The requirements of DreamWings are set for personal private travel. Unlike common private cars, DreamWings includes wings, propellers, and other components. For example, instead of the 5-person seating capacity, the plane's capacity is set for 2 persons in a front-rear-seat configuration, which allows installation for wings along the span direction.

Next, the parking problem is taken into consideration, the area that the whole plane covers should be restricted within the 2.5m×5.3m rectangular space, the size for common parking spaces for private cars. This limit necessitates the use of folding wings, which will be further explored in the following sections.

For the maximum level flight speed, DreamWings is set for greater than 300km/h as a small fixed wing aircraft is at 300km/h. Since DreamWings should be able to fly between cities, its maximum range is set as about 300km to equal the straight-line distance between Shanghai and Nanjing, cities used in this experiment, such a distance can be covered by one hour compared to current typical car journey of 5-6 hours.

3.3 Configuration design

3.3.1 Preliminary overall configuration design

At the vertical take-off mode, the weight of DreamWings should be balanced by the thrust of the propellers. At level flight mode, in order to acquire higher speed, it is better to use the thrust of the propellers as the driving force than to use it to balance the weight which can be instead accomplished by the lift of the wings. The problem is to change the direction of the propeller's thrust from upward at the vertical take-off mode to forward at the level flight mode.

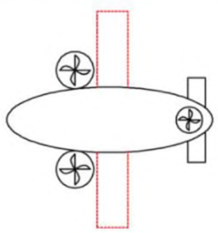
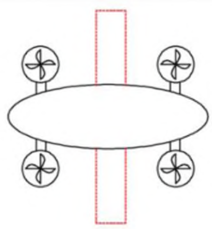
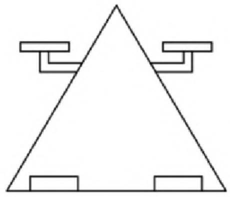
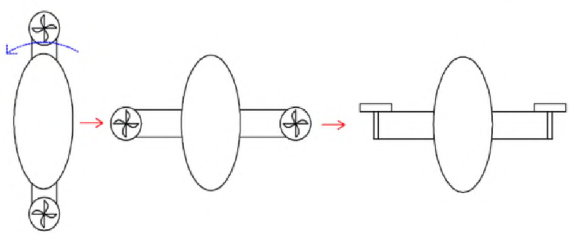
	Configuration 1	Configuration 2	Configuration 3
Sketches	 Figure 1: Top view of configuration 1 in VTOF	 Figure 2: Top view of configuration 2 in VTOF	 Figure 3: Front view of configuration 3 in VTOF
Features	1. Folded wings at the vertical take-off mode 2. Unfolded wings and rotated propellers at the level flight mode		1. Fixed propellers 2. The whole aircraft has to be rotated at the level flight mode
Analysis	1. The propellers are easy to be rotated 2. 3 propellers, less structural weight	1. The propellers are easy to be rotated 2. 4 propellers, more structural weight	1. The whole machine is difficult to be rotated. 2. The posture of the passengers will be rotated, affecting the comfort level for the passengers
Result	According to analysis, configuration 1 is chosen as the final configuration.		

Table 2: Three overall configurations for the design

3.3.2 Empennage design

In order to reduce the structural weight and not to affect the manipulation at the level flight mode, V-tail is adopted. Furthermore, compared to the cruciform tail, the V-tail is more flexible to place the propeller at the rear of the fuselage.

3.3.3 Rotatable and foldable wings and propellers design

	Sketches of transformation(all top views)	Features and problems
Plan 1	 Figure 4: Plan 1 of DreamWings's transformation of rotatable and foldable wings	Difficult attitude control at the vertical take-off mode and during the rotation of the wing

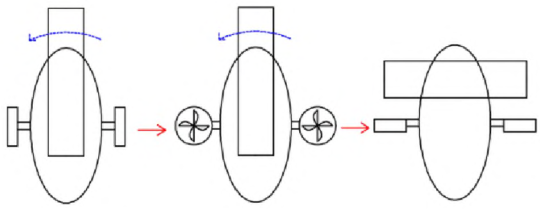
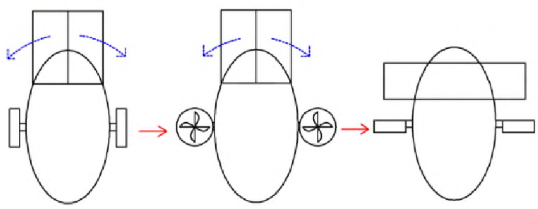
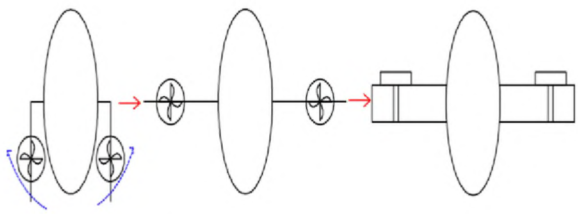
Plan 2	 Figure 5: Plan 2 of DreamWings's transformation of rotatable and foldable wings	At the intermediate mode of the rotation of the wing, the wing may block the flow from the propeller so the exact size of every part remains to be calculated.
Plan 3	 Figure 6: Plan 3 of DreamWings's transformation of rotatable and foldable wings	1. Theoretically feasible 2. More rotatable parts, inducing big structure weight
Plan 4	 Figure 7: Plan 4 of DreamWings's transformation of rotatable and foldable wings	1. A significant drag during the rotation of the wing as there is a greater windward area. 2. Lift calculation during the rotation of the wing may be difficult.
Analysis and result	The feature of Plan 1-3 is that both the wings and the propellers have to be rotated, which would definitely increase structural weight. Compared to Plan 1-3, the propellers are fixed on the wing in Plan 4. When the wing is rotated, the propellers will be rotated simultaneously, thus having less structural weight. So Plan 4 is chosen.	

Table 3: Four plans of rotatable and foldable wings and propellers design

3.4 Sizing of the vehicle (including weight, engine, aero, performance, cost, etc.)

3.4.1 Derivation of mass formula of the flying machine

Total mass:

$$m_{total} = \mathrm{m}_e + m_b + Xm_p \tag{1}$$

For conservation of energy:

$$\mathrm{E_{battery}} = \mathrm{E_{total}} \tag{2}$$

Total energy of the battery:

$$E_{battery} = m_b \rho_b \tag{3}$$

Total energy required from take-off to landing:

$$E_{total} = E_{g1} + E_{vto} + E_{v\to h} + E_h + E_{h\to v} + E_{vl} + E_{g2} \tag{4}$$

For approximate calculation ignoring E_{g1}, E_{g2}, $E_{v\to h}$, $E_{v\to h}$

Therefore,

$$E_{total} = E_{vto} + E_h + E_{vl} \tag{5}$$

(Suppose the air drag f_v during the vertical take-off and landing mode are the same)
Total energy required for vertical takeoff mode:

$$E_{vto} = (m_{total}g + f_v)h_{max} \tag{6}$$

Total energy required for vertical landing mode:

$$E_{vl} = (m_{total}g - f_v)h_{max} \tag{7}$$

Total energy required for level flight mode:

$$E_h = f_h L \tag{8}$$

Suppose the lift-to-drag ratio is:

$$K = \frac{m_{total}g}{f_h} \tag{9}$$

Therefore

$$m_{total} = \frac{m_e + Xm_p}{1 - \frac{g}{\rho_b}(2h_{max} + \frac{L}{K})} \tag{10}$$

3.4.2 Calculation of the radius of the propeller

Thrust of the propeller is: $T = 2\rho\pi R^2(V_0 + v_1)v_1$ [6] (11)

From the formula, the thrust of the propeller is proportional to the rotor disk area can be concluded.

Refer to the data of Ehang184. Its maximum take-off mass is 300kg, propeller radius is 0.75m, and the number of propellers is 8. It can be calculated that the mass per unit rotor disk area is about: 21.22kg/m^2

Use this data to calculate the radius of the propeller (suppose DreamWings uses double propellers so the number of the propellers is 6). The total area of rotor disk area is $S = 6\pi R^2$. The total mass is $m_{total} = 21.22 \times 6\pi R^2$. So the propeller radius is about: $R = \frac{\sqrt{m_{total}}}{20}$. The maximum achievable lift-to-drag ratio based on a typical propeller aircraft is about 20, so the propeller radius is estimated about 1.5m.

3.4.3 Three views of DreamWings

1. Parking mode

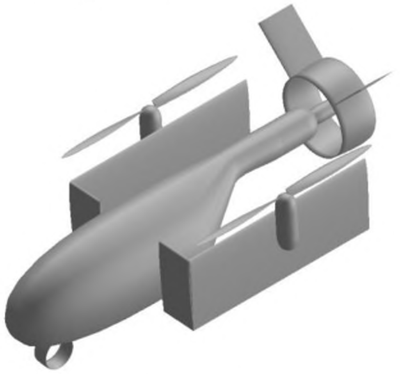


Figure 8: 3D model in parking mode

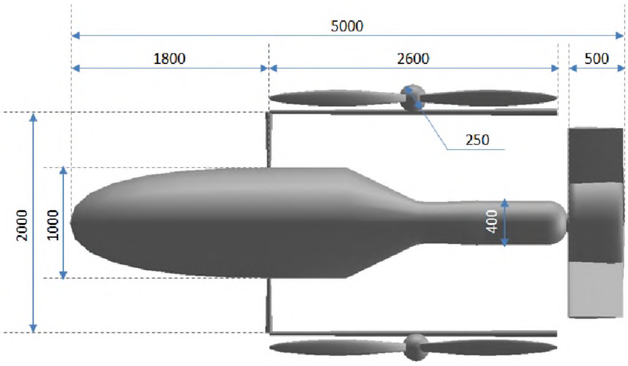


Figure 9: Top view of parking mode

2. Vertical take-off mode

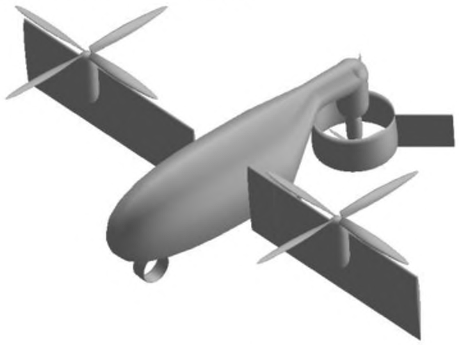


Figure 10: 3D model in vertical take-off mode

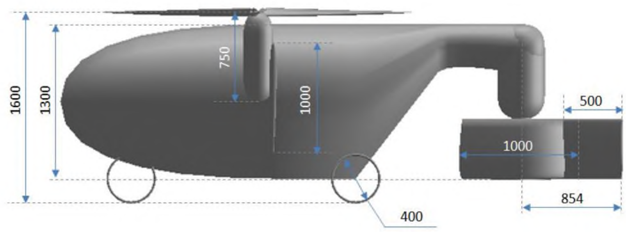


Figure 11: Left side view of vertical take-off mode

3. Level flight mode

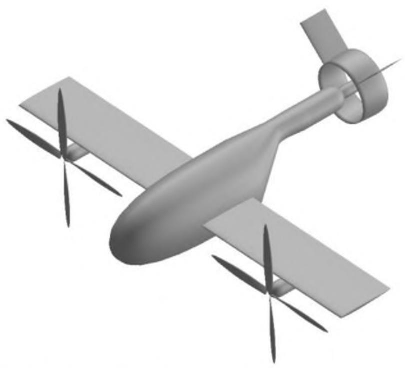


Figure 12: 3D model in level flight mode

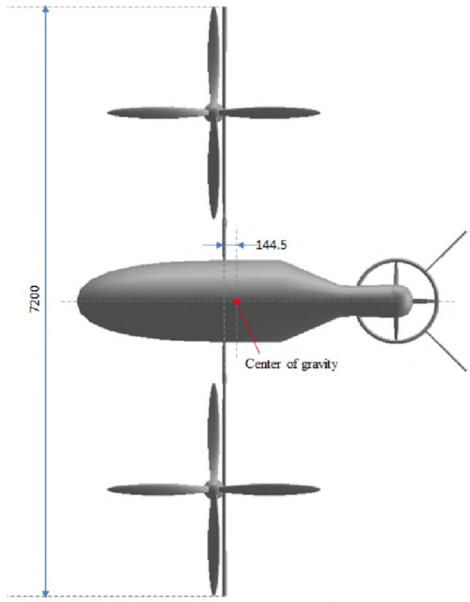


Figure 13: Center of gravity of DreamWings
(top view of vertical take-off mode)

3.4.4 Aerodynamic calculation

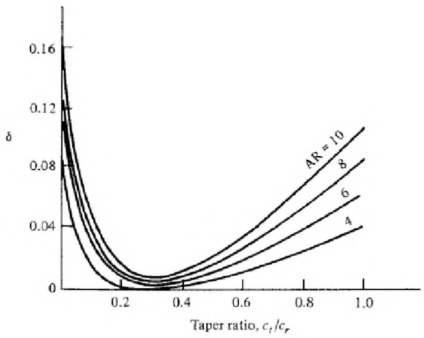


Figure 14: Induced drag factor δ as a function of taper ratio [7]

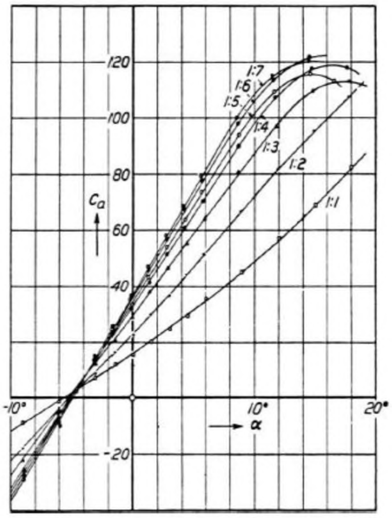


Figure 15: Prandtl's classic rectangular wing data. Variation of lift coefficient with angle of attack for seven different aspect ratios from 1 to 7. The lift coefficient is 100 times the actual value of the coefficient [7]

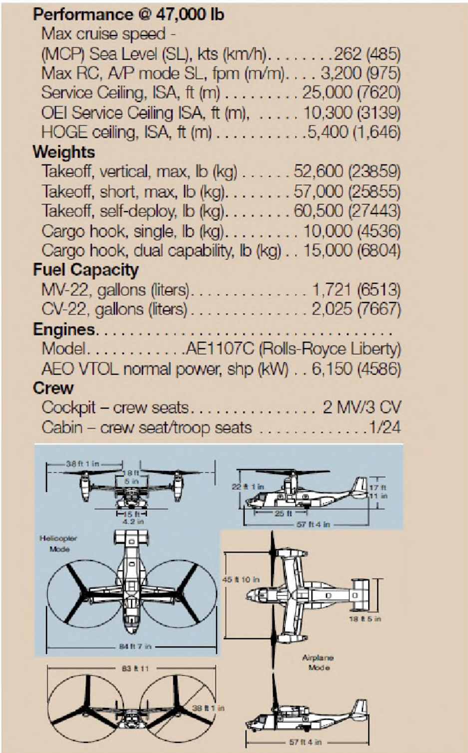


Figure 16: Characteristics of V-22 Osprey [8]

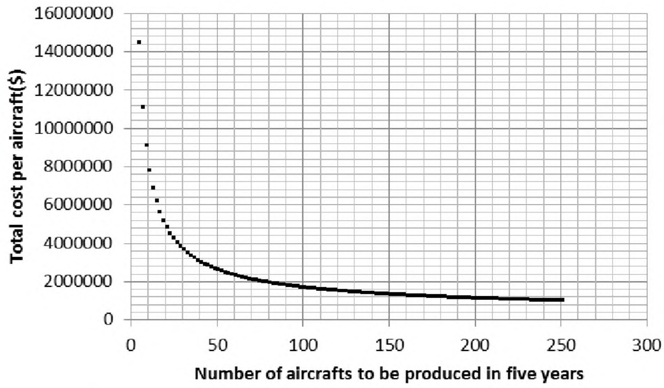


Figure 17: Total cost per aircraft change with number of aircrafts to be produced in five years

First, the lift-to-drag ratio of DreamWings is estimated. At level flight mode, the lift of DreamWings is equal to its total weight and the drag is

$$D = \frac{1}{2} \cdot \frac{0.148}{(\frac{\rho V c}{\mu})^{1/5}} \rho V^2 S + \frac{(1+\delta)}{\pi AR} \cdot \frac{(m_{total} g)^2}{\frac{1}{2}\rho V^2 S} \tag{12}$$

The lift-to-drag ratio $K = \frac{m_{total} g}{D}$. Using international standard atmosphere model (ISA), $\rho = 1.225 kg/m^3, \mu = 1.7894 \times 10^{-5} kg/(m)(s)$.Suppose the cruise speed of DreamWings is $V = 100 m/s$. Chord length $c = 1m$. Wing area $S = 6.2m^2$. Aspect ratio $AR = 6.2$. Refer to Figure 14, for a rectangular wing, $\delta = 0.06$. For m_{total}, refer to formula (10). It can be calculated that the lift-to-drag ratio of DreamWings is about 20.9 and its total weight is about 630.2kg.

Then, the total thrust of the propellers is calculated. Refer to Figure 16, V-22 has 3 blades for each propeller and the radius of the propeller is about 5.8m. The maximum weight to take off vertically is about 23859kg. It can be calculated that the mass per unit rotor disk area is about 75kg/m^2 and for Ehang 184, which has been calculated in 3.4.2, is about 21.22kg/m^2. Refer to these data, the mass per unit rotor disk area of DreamWings is estimated to be about 31kg/m^2. From Figure 9 and Figure 11, the radiuses of the 3 propellers of DreamWings are 1.3m, 1.3m and 0.5m, so the total area of rotor disk area is about 22.81m^2. It can be calculated that the total thrust of the propellers is about 707.1kg.

At vertical take-off mode, the total weight should be balanced by the thrust of the propellers. From the data calculated above, the thrust of the propellers is bigger than the total weight so DreamWings can take off successfully. And it is easy to calculate that the maximum acceleration is about 1.1m/s^2 , so it will take about 1 minute to rise to the height of 1000m. Suppose DreamWings takes off with full thrust, in order to keep it balanced, the center of gravity(refer to Figure 13) can be calculated.

When DreamWings is changing its configuration from vertical take-off mode to level flight mode, the horizontal velocity gradually increases. Refer to Figure 15, the maximum lift coefficient is about 1. Suppose the total weight is only balanced by the lift of the wing, it can be calculated that the minimum flying speed should reach 145km/h. However, at this moment, the wing has not been rotated to the horizontal position completely, so the propellers can also provide some lift. In conclusion, the total lift can balance the total weight at this mode.

At level flight mode, the center of gravity should be controlled in front of the aerodynamic center, so that DreamWings is longitudinal stable at level flight mode, and at the same time, its V-tail can provide enough pitching moment.

3.4.5 Cost calculation

A set of cost estimating relationships for conceptual aircraft design developed by the RAND Corporation, known as “DAPCA, IV”, is used here, the methods used is the Modified DAPCA IV Cost Model (engine and avionics costs are ignored here) (costs in constant 1999 dollars) [9]:

$$\text{Total cost per aircraft} = (445.48 m_e^{0.777} V^{0.894} Q^{0.163} + 635.36 m_e^{0.777} V^{0.696} Q^{0.263} + 879.62 m_e^{0.82} V^{0.484} Q^{0.641} + 48.7 m_e^{0.630} V^{1.3} + 1408 m_e^{0.325} V^{0.822} FTA^{1.21} + 22.6 m_e^{0.921} V^{0.621} Q^{0.799}) / Q \quad (13)$$

where Q is variable here, $m_e = 350kg$, $V = 612\text{km/h}$, $FTA = 4$, \$1 USD in 1999 would be worth \$1.43 USD in 2016.

from Figure 17, if the number of aircrafts to be produced in five years is about 250, the total cost per aircraft is about $1,010,000.

Maximum take-off weight(kg)	630.2
Wing area(m^2)	6.2
Wing span(m)	6.2
Aspect ratio	6.2
Maximum wing loading(kg/m^2)	101.6
Thrust-to-weight ratio	1.1
Cruise speed(km/h)	360
Time of rising to 1000m vertically(min)	1
Cost($)(50 aircrafts produced per year)	1,010,000

Table 4 Calculated data of DreamWings

4 SOME CHANLLEDGES AND POSSIBLE SOLUTIONS

One of the main differences between DreamWings and most designs today is that the energy source for our model is battery. It is a great challenge because battery technology will affect its performance drastically.

In the last 20 years, the energy density of lithium-ion battery is approaching the theoretical limit of 250Wh/kg. In order to acquire much higher battery energy density, scientists have great expectations in lithium-sulfur battery, which has a theoretical energy density of 2567Wh/kg. Currently, the energy density of the lithium-sulfur battery developed by British OXIS Company has exceeded 300Wh/kg. The company expects to develop a lithium-sulfur battery twice the energy density of the current lithium sulfur battery. What's more, hydrogen fuel cells, which have a theoretical energy density of about 3000Wh/kg, were first used in a manned aircraft in 2008. [10, 11, 12].

When calculating the total mass in section 3.4.4, the battery energy density used is the current lithium-ion battery energy density： $\rho_b = 0.72\text{MJ/kg} = 200\text{Wh/kg}$. After analyzing the trend in the development of battery energy density, the value can reach: $\rho_b = 2.7\text{MJ/kg} = 750\text{Wh/kg}$ in the next 5 to 10 years.

As shown from the graph, if the current technology of lithium-ion battery is used, the percentage of battery mass in total mass is about 45%, which is relatively high. In the next 5 to 10 years, the battery energy density can reach twice the energy density of the current battery. The percentage of battery mass in total mass will decrease to about 20%. It is evident that the battery technology has a great effect on DreamWings.

5 CONCLUSIONS

DreamWings can be parked conveniently than other conventional aircraft and it does not need much space to take off and land. Furthermore, it can meet the demands of fast travel between two cities with a typical car journey of about 3-5 hours, which can bring great convenience to the users. After some preliminary calculations and analyses, it can be found that this objective can be achieved in a not so distant future.

However, the realization of this flying machine is also dependent on the development of other technologies and still has large number of challenge to overcome. For example, in order to improve its endurance, a battery with higher energy density is needed. It is hoped that such a concept can provide further motivation for aircraft designers today and in the future.

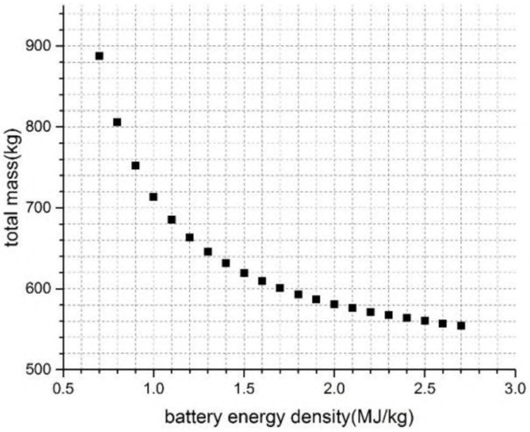


Figure 18: Total mass change with battery energy density

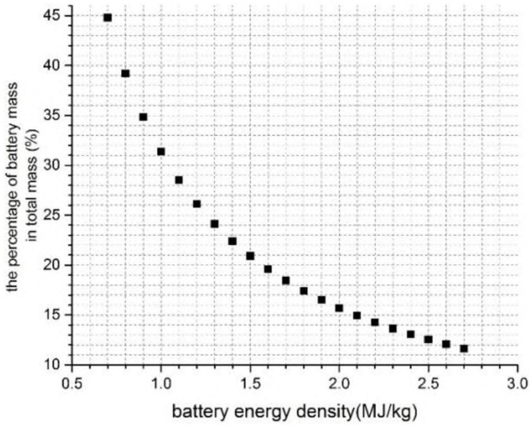


Figure 19: Percentage of battery mass in total mass change with battery energy density

REFERENCES

[1] K. Barnstorff, “The Puffin: A Passion for Personal Flight”, http://www.nasa.gov/topics/technology/features/puffin.html,2010-08-02.
[2] XTI Aircraft Company, “TriFan 600,” http://www.xtiaircraft.com/trifan-600/, 2012.
[3] Martin Jetpack, http://www.martinjetpack.com/home,2010.
[4] 亿航, “EHANG184,” http://www.ehang.com/cn/ehang184,2016.
[5] OpenVSP is a parametric aircraft geometry tool, which allows the user to create a 3D model of an aircraft defined by common engineering parameters. The predecessors to OpenVSP have been developed by J.R. Gloudemans and others for NASA since the early 1990's.
[6] 曹义华. 现代直升机旋翼空气动力学, 北京：北京航空航天大学出版社, 2015,pp.16.
[7] J.D. Anderson, Fundamentals of Aerodynamics. New York, America: McGraw-Hill, 2011, pp. 371-375, 440-444.
[8] Bell Helicopter, Boeing Rotorcraft Systems, V-22 Osprey 2010 Guidebook, 2010, p.34.
[9] D.P. Raymer, Aircraft Design: A Concept Approach. Reston, Virginia: American Institute of Aeronautics and Astronautics, Inc., 2006, pp.567-570.
[10] 郭浩，崔勇. 高比能量锂硫电池电解液的发展分析. 城市建设理论研究，2015(22).
[11] 贾旭平. 英国 OXIS 公司的锂硫电池. 电源技术，2015(1).
[12] D. Gross, Fuel cells in aircraft. Cleantech magazine, November 2008.

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CONCEPTUAL DESIGN OF A SUBMERSIBLE AIRCRAFT WITH MORPHING TECHNOLOGY

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Key words: Morphing technology, OpenVSP, RANS and VOFmethods, Aerodynamic and hydrodynamic characteristics, Submersible aircraft.

Abstract. *The conceptual analysis and design is presented for an advanced, submersible aircraft with morphing technology. Radically different operating conditions between in-air-flight and under-water-cruise present distinct challenges which are met by using morphing technology, leading to different geometries for the two flight conditions. The morphing is implemented using a hybrid approach of mechanical links and smart memory materials, combined with active actuators and sensors embedded within the structures. Typical design tasks were carried out using OpenVSP and results were presented for the preliminary design of the vehicle. Top-level design parameters were determined using a sizing code in MATLAB with reference to data in literature. RANS and VOF methods from ANSYS Fluent were used to estimate the full-aircraft aerodynamic and hydrodynamic characteristics. The concept can be further developed into the next stages to evaluate requirements on systems, energy, and detailed performance characteristics.*

1 INTRODUCTION

Nowadays UAVs (Unmanned Aerial Vehicles), commonly known as drones, are gradually taking up more places traditionally occupied by manned aircraft because of its advantageous features in operational flexibility, security and low-cost. UAVs can carry out missions which are considered too dangerous and inappropriate for manned aircraft [1]. They originated mostly in military applications. In fact, high maneuverability coupled with the ability to operate with the utmost stealth is one of the prerequisites for any successful UAVs in defense applications.

A submersible aircraft capable of flight in air, under water cruise, surface takeoff and landing is a combination of a seaplane and an underwater vehicle [2]. It is supposed to be able to fly as well as cruise under water. Taking off from the surface of the water is also intended. The submersible aircraft integrates the advantages of three entirely different vehicles: 1) high maneuverability and attacking ability of a UAV; 2) the voyage abilities of a ship and 3) the stealth of a submarine.

Compared to traditional UAVs, the morphing submersible aircraft needs to satisfy the requirements of various missions [3]. A flying submarine was supposed to be used on the open sea for attacks on hostile ships and near shore targets. It can also land on the water and transform itself into an underwater vehicle that will loiter under water for a long period of time until the danger has passed [4]. It could take off from a safe location to fly to its target areas at minimum altitude with minimum chance of being detected. At the completion of its underwater mission it could travel as a submersible to a location best suited for takeoff and return to the mother ship [5].

The desire for an aircraft with such capabilities is certainly not a new idea. Former Soviet Union and the United States had preliminary studies into this technology early in World War II, but it was eventually abandoned, because the technologies required were too far ahead of that period. In 2008, Defense Advanced Research Projects Agency (DARPA) [6] and NASA [7, 8] as well as several aerospace companies, have begun exploring possible morphing configurations. But combining the two epoch-making vehicles has proved a huge challenge. There are still many technical problems which remain to be solved:(1) Conflicts between the weight requirements of diving and flying; (2) Different structural requirements for operating in water and air; (3) Different cruising environment between water and air; (4) Selection of propulsion systems

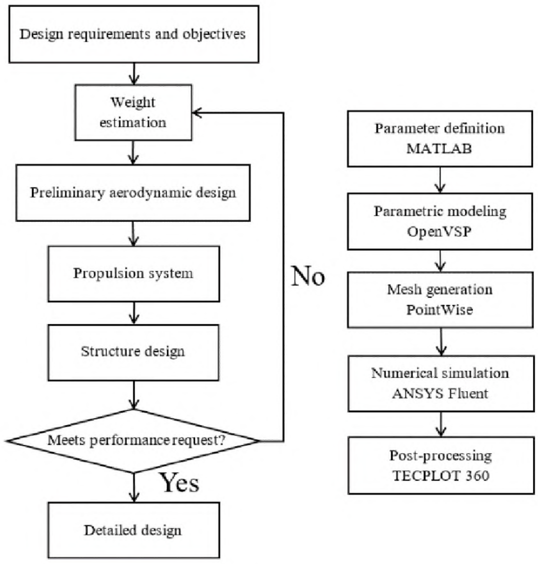


Figure 1: Flowchart of preliminary design

In recent years, advancements in smart materials and structures have made the development of submersible aircraft with morphing technology plausible [9]. However, there is rarely in-depth research and very little relevant information is available in the public domain. It is extremely important to systematically formulate the requirements and to carry out feasibility analysis for this design concept. The purpose of this paper is to present the conceptual design of such a submersible aircraft concept with BWB and tailless configuration and to formulate some sensible requirements for the future development of morphing configurations.

2 CONCEPTUAL DESIGN

2.1 Conceptual design process

The conceptual design is a trial and error process driven by mission requirements and knowledge from relevant fields such as aerodynamics, flight mechanics, and propulsion, etc. The goal of the conceptual design phase is to explore a few potential concepts and to optimize them as much as possible [10]. The whole process consists of a sequence of steps and the related software, as illustrated in Figure 1. During this conceptual phase, steps in this flow chart will be repeated until all the design parameters meet the requirements.

Design requirements	Value	units	Design requirements	value	units
Range	250	km	Cruising	<10	km/h

			speed(water)		
Cruising speed(air)	190	*km / h*	Payload	100	*kg*
Wing span	<7	*m*	Service ceiling	1000	*m*

Table 1: Design requirements

It typically starts by identifying the requirements or capabilities, which are determined in a market survey, in order to define the mission requirements for a conceptual aircraft. The design requirements and objectives of the submersible aircraft are listed in Table 1.

Following the formulation of a design proposal, the next step is to perform initial design iterations until all the top-level parameters meet the design requirements. Total drag and power requirements from the engine will be estimated based on the performance requirements. It also involves the estimation of the weights and the choice of aerodynamic configurations that will be best suited to the mission requirements stated in the design proposal.

In general, early design analysis is dominated with simple empirical, semi-empirical or statistical methods, with some limited use of computational methods such as computational fluid dynamics (CFD). The ultimate objective during preliminary design is to gather sufficient data in order to convince both the customer and management team that such a design is plausible in terms of both technical performance and financial resources, and can go into next stages of development.

2.2 Weight estimation

The purpose of this section is to provide a methodology for rapid estimation of airplane component weights. The empirical approach is preferred here to save as much engineering man-hours as possible.

For reasons of brevity, only the following component weights are presented in the paper: structure weight (W_{Struct}), powerplant weight(W_{pwr}), battery (W_{batt}) andfixed equipment weight (W_{pwr}). The airplane empty weight (W_E) is expressed as:

$$W_E = W_{Struct} + W_{pwr} + W_{batt} + W_{pwr} \tag{1}$$

(1) Structural weight estimation

According to previous research, it will be assumed that the ratio of $\frac{W_{Struct}}{W_{to}}$ is 0.3, similar to the average value of UAVs of similar size. A conservative assumption is to apply a 15 percent weight reduction to structural weight by using composites. Therefore, the ratio of $\frac{W_{Struct}}{W_{to}}$ is finally set as 0.3*(1-0.15) =0.255.

(2) Powerplant weight estimation

This UAV will use a single electric-powered engine as the propulsion system. Powerplant weight can be estimated through empirical formula, which can be expressed as:

$$W_E = F_{thrust} \times V_{cruise} * \frac{20}{75} \tag{2}$$

in which, F_{thrust} can be estimated as:

$$F_{thrust} = W_{TO} \times \frac{T}{W} \tag{3}$$

in which, $\frac{T}{W}$ refers to thrust weight ratio.

(3) Battery weight estimation

The weight of battery is affected by many factors such as output power, time of duration, battery energy density, etc., and it can be assumed that the battery energy density will reach 700Wh/h in 2020. The time-frame based on analysis of current technology trends, thus battery weight can be simply express as:

$$W_{batt} = F_{thrust} * \frac{\text{Range}}{3600 \times \text{energy density}} \tag{4}$$

(4) Weight estimation of fixed equipment

For reasons of brevity, only the following component weights are considered[11]: electrical system, flight control system and water-jet propulsion device (20kg).

All of them can be estimated using empirical formulas which are given below:

$$W_{es} = 7.46 + 0.008 \times W_{TO} \tag{5}$$

$$W_{fc} = 0.027 W_{TO} \tag{6}$$

According to the weight estimation process, it is noted that all component weight is given in ratios relative to gross takeoff weight.

$$W_{TO} = [f(W]_{TO}) \tag{7}$$

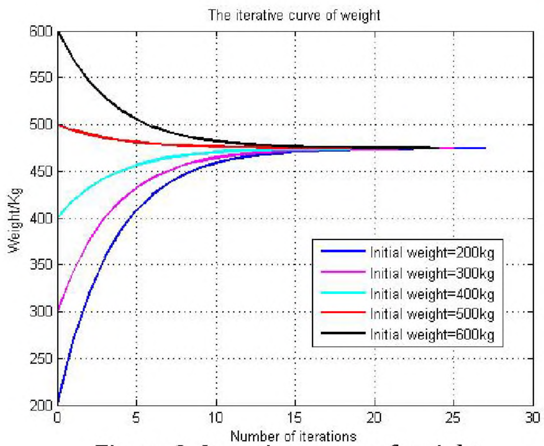


Figure 2: Iterative curve of weight

In order to obtain the final takeoff weight value, an initial value will be set and the solution is achieved with an iterative process. Initial takeoff weight can be substituted into the right-hand side, and then a second takeoff weight value can be calculated. This process is repeated until convergence is achieved which is set to be 0.1% between the two iterations.

Four different initial values are used to obtain the final takeoff weight, as shown in Figure 2. It is obvious that the same final value can eventually be reached from different initial values. The following table lists the final weight value for each component. As can be seen from Table 2, battery weight accounted for more than 34 percent of the overall takeoff weight. Therefore, to increase battery energy density and reduce weight to further improve the performance of the vehicle is a considerable challenge.

Component	Weight(kg)	weight fraction	Component	Weight(kg)	weight fraction
Structures	128	27%	Powerplant	51	10.8%
flight control system	13	2.7%	water-jet propulsion device	20	4.2%
Battery	161	34%	Propeller	10	2.1%
electrical system	11	2.3%	Total	474	100%

Table 2 Weight data from initial estimation

2.3 Aerodynamic configuration design

Wing parameters	Value	units	Wing parameters	value	units
Wing span	6.5	*m*	Area	12.2	m^2
Aspect ratio	5.37		Twist angle	-3	°

Wing installation angle	0	°	Dihedral angle	4	°
Swept angle(LE)	55	°	Airfoil	NACA 65_1012	

Table 3: Wing parameters

(1)Overall configuration

A Blended Wing Body can effectively reduce structural weight due to better use of structural strength [12]. The potential advantages of the BWB approach are better aerodynamic performance for reducing both induced drag and wave drag [13]. The BWB configuration is adopted here as the basic geometry with the central lower fuselage designed as the shape of a high-speed boat, the wings are smoothly blended into the body. The BWB configuration is used for both aircraft and underwater gliders. Taking all operating situations into account, this design will present configuration characteristics of both seaplane and a BWB plane, leading to an effective hybrid wing body configuration.

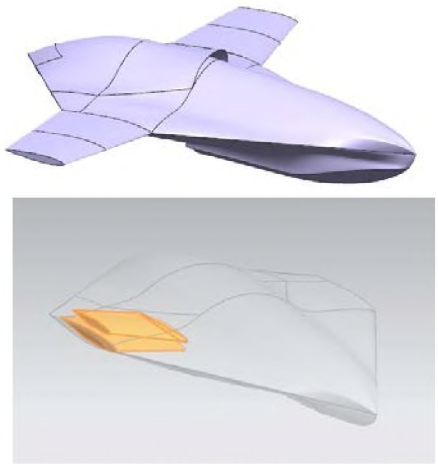


Figure 3: Commparison between air configuration and underwater configuration

(2) Selection of wing parameters

Wing design plays a key role in the whole conceptual design phase. Wing geometries are computed by empirical, semi-empirical or statistical methods. Related parameters are listed in Table 3.

2.4 Thrust/Weight ratio and wing loading

T/W and W/S are the two critical parameters affecting the aircraft performance.

(1) Cruise condition

For steady level flight, speed is a function of wing loading ($\frac{W}{S}$), air density (altitude) ρ , and lift coefficient C_L

$$V = \sqrt{\frac{2}{(\rho C_L)\left(\frac{W}{S}\right)}} \tag{11}$$

T/W for cruise can be defined as

$$\frac{T}{W} = \frac{1}{L/D} = \frac{qC_{D0}}{W/S} + (\frac{W}{S})\frac{K}{q} \tag{12}$$

in which : q --dynamic pressure ; S --wing area ; K --induced drag coefficient; C_{D0} --zero-lift drag coefficient

(2) Stall speed constraint

Wing loading, which can be estimated from stall speed V_{stall} and diving speed, is affected by aerodynamic, structural characteristics and propulsion. Wing loading is constrained by approach speed:

$$\left(\frac{W}{S}\right) = 0.612 V_a^{\ 2} C_{La} \left(\frac{M_0}{M_L}\right) \tag{13}$$

Relationship between stall speed and approach speed

$$V_a = (1.2 \sim 1.3) V_{stall} \tag{14}$$

V_{stall} can be calculated from

$$W = 0.5 \rho V_{stall}^{\ 2} S C_{L\max} \tag{15}$$

in which, V_a --approach speed ; $\left(\frac{M_0}{M_L}\right)$ --ratio of takeoff mass and landing mass ; C_{La} --max lift coefficient at landing

(3) TOL constraint

For given takeoff distance, wing loading can be determined by

$$\left(\frac{T}{W}\right)^{-1.35} = \frac{C_{Lus}}{k_e\left(\frac{W}{S}\right)}\left\{TOL - 120\left[1-\left(\frac{T}{W}\right)\right]\right\} - \frac{6}{k_e}\left(\frac{C_{Lus}}{\left(\frac{W}{S}\right)}\right)^{\frac{1}{2}} \quad (16)$$

in which: C_{Lus} --max lift coefficient at takeoff condition ; $K_e = 0.1$

(4)Wing loading constrain under gust

The operations under gust take-off environment for UAV should be regard as an important factor. The lower limit of wing loading is expressed as below:

$$\frac{W}{S} \geq \frac{2.7V_D A}{\left(0.32 + 0.\frac{16A}{\cos\Lambda}\right)[1-(M_N\cos\Lambda)^2]^{\frac{1}{2}}} \quad (17)$$

in which, A -- aspect ratio , Λ -- sweepback angle at 25% chord ; M_N --cruising Mach ; V_D -- design diving speed

T/W and W/S are interrelated and need to be cross-checked once determined using a number of different criteria. Therefore constraint plotting is a useful method to assist in the choice of T/W and W/S. The limiting conditions can be plotted on the boundary diagram as shown inFigure 4. With the help of constraint diagram a reasonable combination of T/W and W/Scan be decided in the design region as shown in Figure 4. To ensure enough variable margins, T/W and W/S (cruising condition) are set as 0.4 and $700N/m^2$.

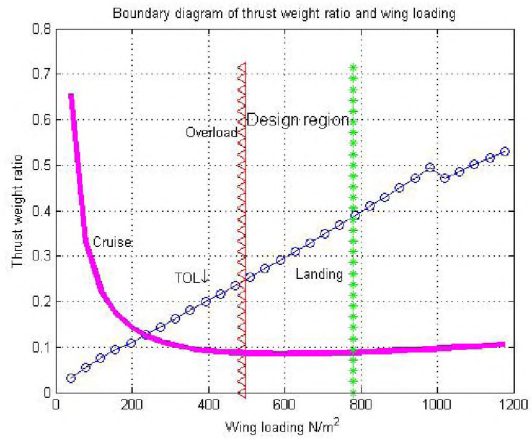


Figure 4: Boundary diagram of thrust weight ratio and wing loading

3 AERODYNAMIC AND HYDRODYNAMIC CHARACTERISTICS ANALYSIS

Following the conceptual sizing of the configuration parameters, the aerodynamic and hydrodynamic characteristics of the designed submersible aircraft are now analyzed by using 3D RANS and VOF (Volume of Fluid) methods in ANSYS Fluent.

3.1 Modeling in OpenVSP

A highly interactive, parameter-based aircraftmodel has beencreated in OpenVSP, which was developed to generate detailed 3-D geometric models quickly and smoothly. The models allow a visualinspection of the geometry parameters used in the conceptual aircraft design[14]. Fast and accurate geometry modeling also allows the designer to use more complex analysis methods such as CFD earlier in the design process and therefore reduce reliance on empirical equations in conceptual design. Files of IGES and STL format were used to transfer the geometry to grid generation software after parametric modeling task.

3.2 Discretization of morphed wing

The grid generation was performed using Pointwise. In order to increase the accuracy of the flow analysis, a structured mesh was selected in full UAV configuration. Hexahedral elements are used to generate the mesh in the boundary layer. In order to minimize the boundary effects on the flow near the plane, the control volume was three times the reference length away from the plane. Grids around the plane, leading edge and tailing edge was shown in Figure 5. The resulting mesh contained 1724464 cells in folding mode and 1616128 cells in its unfolded state.

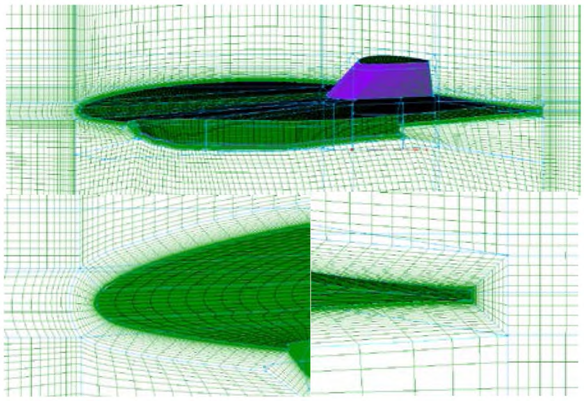


Figure 5: Full configuration volume mesh

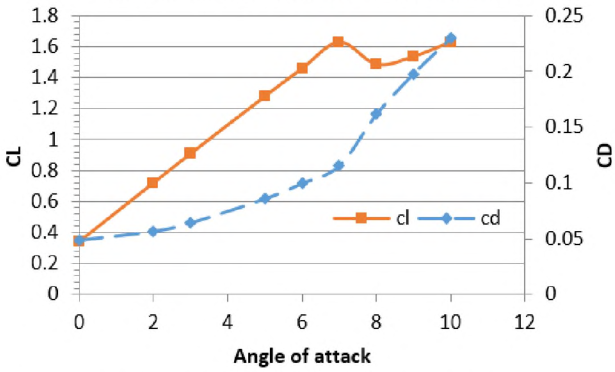


Figure 6: Drag and lift coefficients for the full configuration

3.3 Air cruising state

All other faces bounding the control volume were set as pressure farfield. The simulations were performed in Fluent 16.1 using the double precision 3D solver and the Spalart-Allmaras viscous model [15]. The results were obtained from running steady-state simulations at constant free stream velocity and for angles of attack between 0 and 10 degrees. The air speed was considered to be equal to approximately 0.155 Mach (Re=1.44×10^{7}).
Calculated lift and drag coefficients for the full configuration are shown in Figure 6. With the increasing of the angle of attack, flow separation leads to a slight drop in lift. Maximum lift-drag ratio is about 15 at 6°angle of attack and it then drops rapidly as the angle of attack increases.

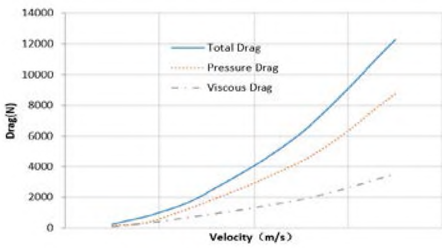


Figure 7: Drag curve

3.4 Underwater cruising state

Submersible aircraft can fly low over the sea until it nears its target at cruising speed. The hydrodynamic characteristics under water were simulated by ANSYS Fluent at speed from 1 to 7 m/s and zero angle of attack.

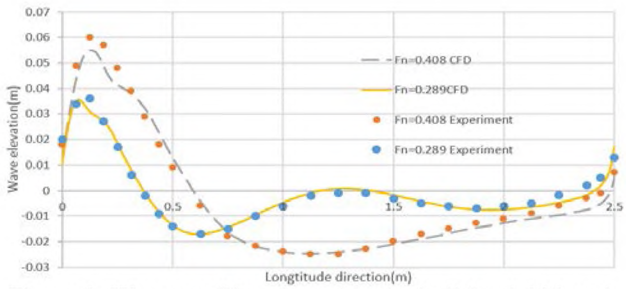
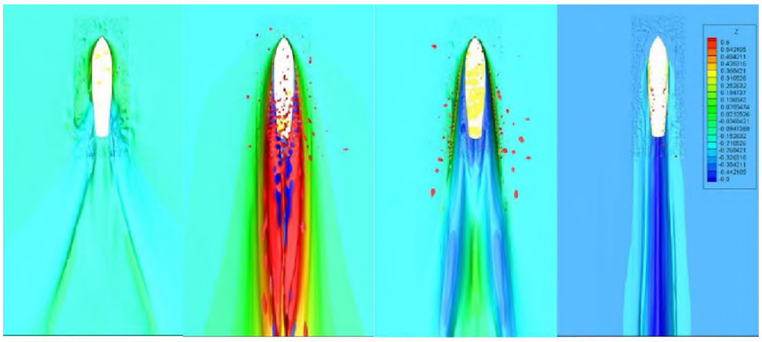


Figure 8: Wave profiles alongside the hull for 0.289 and 0.408 Froude number

As shown in Figure 7, drag increases in parabolic with the increase of speed. For the submersible aircraft, excessively high speed brings no significant advantage but large drag. Therefore, 7km/h is considered an economic cruising speed. At these speeds, the characteristics of the air and water flow – defined by a parameter known as the Reynolds number – are roughly the same, so the UAV’s control surfaces should remain effective in both environments.

3.5 Water takeoff process

Compared to the air and water cruising conditions, the water takeoff process is more important because the submersible plane will withstand maximum drag during this condition and it will determine whether this configuration can takeoff successfully from water surface.



V=5.65m/s V=8.57m/s V=10.46m/s V=15.71m/s

Figure 9: Wave patterns for different Froude number

A) Wigley model validation case

For hydrodynamic calculation validation, the Wigley parabolic model is used to obtain the optimal mesh density and to determine the size of the flow field. The SST model was chosen as the turbulence model while the thickness of the first boundary-layer mesh was set as 10^{-5} m. The Wigley model, with 2.5 meters in length and 0.25 in breadth, was fixed to sink with different inflow velocity.

Comparison with the experimental data from the Resistance Committee of the 17-ITTC report [16] shows that the wave elevation alongside the hull are consistent with the experiment observations shown in Figure 8. The average relative error between CFD drag coefficient and the experiment is 2.85%.

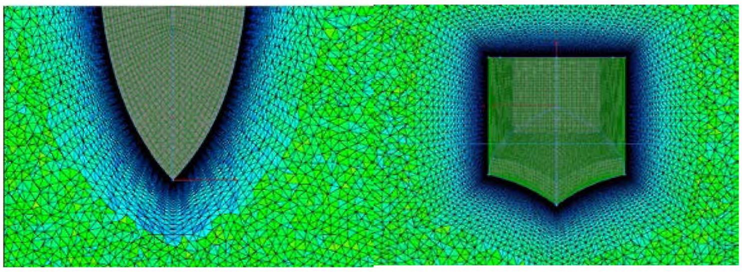


Figure 10: T-Rex grid section

B) Hydrodynamic characteristic analysis in the water takeoff process

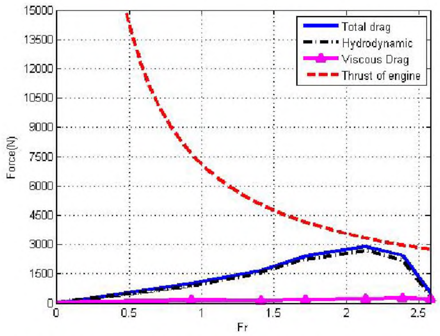


Figure 11: Thrust and drag history during water take-off period

In this section, ANSYS Fluent was used to obtain forces by solving the Navier-Stokes equations with RNG k-e model and VOF method. Hull volume mesh is generated using Pointwise's anisotropic tetrahedral extrusion method, aka T-Rex, which is suitable for application in conceptual design because of its high automation in creating unstructured boundary layer meshes on complex geometries.

The takeoff process was divided into several stages based on speed. Each velocity corresponds to an initial displacement. Hydrodynamic performance will be available in each condition when given initial velocity and water level. Wave patterns with different Froude numbers were shown in Figure 11. With the increase of the sliding speed, the wave region became narrower and narrower.

Figure 11 shows hydrodynamic drag, total drag, and required engine thrust during water takeoff. It can be seen that the hydrodynamic drag first increases then decreases with the increase of sliding velocity [17]. After the maximum drag condition, total drag shows a sharp decline because of the fast drop of the waterline and then the plane left the water gradually. Figure 11 indicated that the submersible aircraft can take off from the water when the maximum thrust weight ratio reaches 0.622. Main performance parameters are listed in Table 4.

Performance parameter	Value	Units	Performance parameter	Value	Units
Takeoff thrust-weight ratio	0.622		Range (air)	800	km
Range (under water)	50	km	Cruising speed (air)	190	km/h
Cruising speed (under water)	7	km/h	$C_{L\max}$ (takeoff)	1.8	
Ceiling	1.5	km/h	$C_{L\max}$ (landing)	1.7	
Wing loading	700	N/m^2	Cruising trust-weight ratio	1.4	
Maximum lift-drag ratio	15				

Table 4: Main performance parameters of the vehicle

4 ANALYSIS OF MORPHING MODE

To accommodate different requirements from various mission segments, it is a common idea to propose the use of a morphing configuration. However, the use of morphing technology on production aircraft is still very limited, largely due to shortcomings of the state of the art. The concept in the work is an unmanned airvehicle, capable of long range cruising with unfolding wings, and fast diving with folded wings. Various operational conditions limit the choice of morphing structures. Several constraints must be satisfied:

(1) In order to reach diving weight, there must be enough space inside the wing for water-filling.

(2) Morphing structure should be simple and light to avoid being overweight.

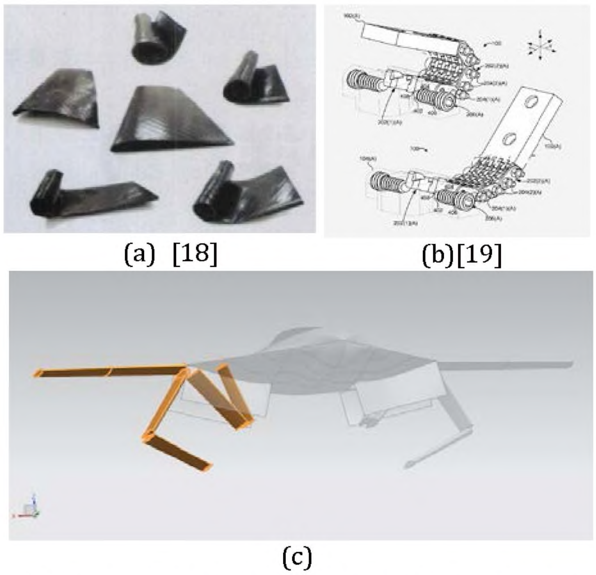


Figure 12: Folding wings with morphing technology

Two possible solutions were purposed to meet these requirements based on some preliminary analysis of the morphing technology.

4.1 Shape memory polymer (SMP)

SMP (shape memory polymer, Figure 12 (a)) is a type of high modulus material with a special memory function. A morphing wing could be made of SMP, which can unfold automatically when being activated by heat, high-frequency optical signal or electrical signals. According to the chief engineer of the SMP manufacturer, an SMP morphing wing can be folded hundreds of times and the whole deformation process will only take several minutes[18].

4.2 Dynamic fulcrum hinge

A variant mechanism using dynamic fulcrum hinge and elastic deformation skin was designed to realize the continuous folding operation[19]. This morphing mechanism can also meet the deformation requirements in the current application.

The dynamic fulcrum hinge (Figure 12 (b)) which is currently used in laptop connections, was selected to connect and brace the wing sections. Part of doing that, it seems, is extending the hinge. As it opens up, the hinge rolls outward, pushing one section of the wing slightly farther back from the other as shown in the figure above. Compared to the traditional folding mechanism, the dynamic fulcrum hinge mechanism is simpler and can effectively save interior space in the wing. The trajectory of each part could be well designed, so there is less gap whether they are completely closed or unfolded [20]. In addition, a locking device strong enough to maintain the deformation is required. The unilateral wing was made up of three foldable wing-sections. It should be noted that the folding mechanism proposed here remains at concept stage and more detailed work is necessary, including the analysis of loading conditions.

5 CONCLUSIONS AND OUTLOOK

5.1 Conclusions

A submersible aircraft concept based on hybrid wing-body with displacement hull was proposed using a novel morphing concept. Initial sizing was carried out by iterative methods based on design requirements of payload and range. OpenVSP was used to provide models for aerodynamic and hydrodynamic analysis. The aerodynamic and hydrodynamic performance analyses using ANSYS Fluent were carried out to evaluate the feasibility of this design concept. In addition, two feasible morphing modes were proposed and some initial analysis was given.

5.2 Future work

Given the novel nature of the design, there is still much scope for further, more detailed studies, in particular in the following aspects, before a realistic design can be achieved.

(1) The choice of wing skin materials will have a major effect on the performance of the UAV. It is necessary to employ an elastomeric flexible skin that will accommodate the morphing wing in a reliable manner.

(2) The structural design aspects should be considered by using finite element methods in the future, considering all of the loading conditions.

(3) Systems, propulsions, and control aspects of the vehicle will need to be considered in more detail.

In summary, the concept proposed in the current work represented a novel hybrid capable of two distinct flight modes and its design could promote the advances in several technological areas.

REFERENCES

[1]. Tice, B.P., Unmanned Aerial Vehicles: The Force Multiplier of the 1990s. *Airpower Journal*, 1991: p. 41-54.

[2]. *Wikipedia*, T.F.E., Seaplane. 2016.

[3]. Chong, Y., Overall Design of Morphing wing UAV and Control Experiment. 2013, *Nanjing University of Aeronautics and Astronautics*. p. 61.

[4]. Mahmood, N., Pentagon Working On Submarines That Can Fly. 2010.

[5]. Network, U.R., Pentagon plans flying submarine. 2010.

[6]. Weiss, P., Wings of change: Shape-shifting aircraft may ply future skyways. *Science News*, 2003. 164(23): p. 359-359.

[7]. Wlezien, R., et al., The Aircraft Morphing Program. Proceedings of SPIE - *The International Society for Optical Engineering*, 1998. 3326.

[8]. Anna-Maria R., M., et al., Research Activities Within NASA"s Morphing Program. *Research Activities Within Nasas Morphing Program*, 1999.

[9]. Talley, D., et al. Methodology for the Mission Requirement Determination and Conceptual Design of a Morphing UCAV. in A*iaa "unmanned Unlimited" Technical Conference, Workshop and Exhibit*. 2004.

[10]. Brandt, S.A., Introduction to Aeronautics: A Design Perspective. Soton.ac.uk, 2004(1).

[11]. Roskam, J., Component weight estimation. 1989.

[12]. Thomas, R., C. Burley and E. Olson, Hybrid Wing Body Aircraft System Noise Assessment with Propulsion Airframe Aeroacoustic Experiment. *International Journal of Aeroacoustics*, 2012. 11(3-4): p. 369-409.

[13]. Odle, R.C., D. Roman and B.K. Rawdon, Blended wing body cargo airplane. 2013, US.

[14]. Gloudemans, J., P. Davis and P. Gelhausen. A rapid geometry modeler for conceptual aircraft. in *Aerospace Sciences Meeting and Exhibit*. 1996.

[15]. Galantai, V.P., Design and Analysis of Morphing Wing for Unmanned Aerial Vehicles. Master, 2012.

[16]. Kajitani, H., et al., The Summary of the Cooperative Experiment on Wigley Parabolic Model in Japan. 1983.

[17]. Qiu, L. and W. Song, Efficient Decoupled Hydrodynamic and Aerodynamic Analysis of Amphibious Aircraft Water Takeoff Process. *Journal of Aircraft*, 2015. 50(5): p. 1369-1379.

[18]. Zhang, J., Morphing Wing :Waving like birds(in Chinese). *Modern military*, 2005(08): p. 59-60.

[19]. USPTO, Detais behind Microsoft's Patent Pending Surface Book Hinge. 2016.

[20]. Kastrenakes, J., This is how Surface Book's crazy hinge works. 2015, *The Verge*.

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EFFECT OF THE PROGRAM OF AEROSPACE DESIGN UNITED COURSES WEBSITE FOR UNDERGRADUATE AIRCRAFT DESIGN EDUCATION

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Key words: Aircraft conceptual design, United course, Website structure, Education process.

Abstract. *The Program of Aerospace Design United Courses (PADUC) website is a part of PADUC launched by Beihang University. Its development is divided into two stages. The first stage is to initiate "Virtual Design Workshop" (VIDEW) based on "Beihang-Purdue Joint Aircraft Design Courses Program" by Beihang University. The second stage is to establish the PADUC website. This site includes a Student Group and a Teacher Group. Its main modules are Personal Center, Curriculum Center, Design Center, Question & Answer, Experience Sharing, and Data Center. As a bridge between the member universities and students, the site provides a learning and exchange platform for students, teachers and experts using the website. It also creates conditions for the users to acquire knowledge and inspiration, and offers a platform of support for PADUC.*

1 INTRODUCTION

Aircraft Conceptual Design of Beihang University (BUAA) is a professional course for students majoring in aircraft design. It won the titles of 'Beijing Excellent Course' in 2006 and 'National Excellent Course' in 2008. As a compulsory course for an aircraft design major, the course introduces the general design of aircraft, especially the conceptual design process, to enable students to master the basic concepts, the main ideas and basic theories & methods. It also helps students to understand the general design methods and technology of modern aircraft. By paying attention to comprehensive conceptual design as a guide, this curriculum encourages students to cultivate their innovative ability and team spirit. Thus, it inspires students to utilize learned knowledge to actively solve problems in the design team. It also lays the foundation for future practical work.

Aerospace design is a systematic project that requires teamwork. Not only is teamwork essential to the industrial sector, but teamwork and exchanges between colleges both play critical roles in promoting each other. During 2011 and 2013, Beihang University launched 'Beihang-Purdue Aircraft Design Joint Courses Program' [1], based on the National Excellence Course Aircraft Conceptual Design. This program explored several joint teaching approaches, including joint student design teams, and face to face and remote lectures. A website called 'Virtual Design Workshop (VIDEW, http://aero.buaa.edu.cn)' [2, 3] which is similar to 'Second

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Life' [4, 5], was developed to provide a network platform to accumulate and share students' aircraft design concepts.

On the basis of preliminary exploration of VIDEW, Beihang University launched the 'Program of Aerospace and Design United Courses' (PADUC) in early 2014. Now PADUC has acquired the full support from members, such as Beihang University, Beijing Institute of Technology, Nanjing University of Aeronautics and Astronautics, Shanghai Jiao Tong University and Purdue University. It aims at gathering excellent resources of aerospace design courses from around the world, providing a communication and sharing platform, as well as a professional design support cloud. This program will explore cooperation through 'in-depth sharing of resources, stimulating innovation, collaborative design communication'. With the contribution of each member course, we believe PADUC can drive the overall improvement and sustainable development of the aerospace design education community.

2 WEBSITE STRUCTURE

The PADUC website contains seven modules. As shown in Figure 1, there are Personal Center, Curriculum Center, Design Center, Question & Answer, Experience Sharing and Data Center. The following is a brief introduction to main modules.

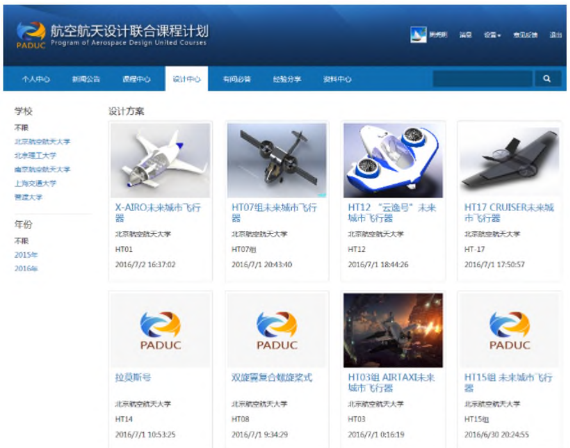

Figure 1: Seven modules of the PADUC website.

2.1 Design Center

The Design Center module, as shown in Figure 2, includes the design schemes of all the teams since the implementation of PADUC. It provides two key words: 'school' and 'year', to scan the design schemes. In each scheme, it displays the results of each stage, the team members, the course and the parent project information. The design scheme only shows the second and third stages. The result of each stage uploads design pictures, 3D models, the report and videos. The report can be downloaded by teachers.

Figure 2: The Design Center.

2.2 Curriculum Center

The Curriculum Center module contains the related courses offered by the PADUC members and the previous projects, as shown in Figure 3. It provides a reference for the students' team scheme design.

Figure 3: The Curriculum Center.

2.3 Question & Answer

As shown in Figure 4, the Question & Answer module provides a communication platform for website users. Users can ask their own questions and reply to others' questions in this module. The module also sets up a leaderboard in which a corresponding score can be obtained by answering a question. In the final examination assessment, the teacher will add the corresponding score to the students according to the leaderboard. Based on this module, students can not only solve the problem in the limited class time, but also receive answers from other students, teachers, and experts after class.

Figure 4: The Question & Answer.

2.4 Data Center

Various data, such as pictures, videos, models, literatures and software, can be uploaded or downloaded in the Data Center. Here students can obtain various types of professional information, and share their own resources. The module is shown in Figure 5.

Figure 5: The Data Center.

2.5 User Groups

This site includes a Student Group and a Teacher Group, corresponding to different permissions for each module. Students register and use the Student Group, teachers and experts register and use the Teacher Group.

- Student Group

Student Group can use all the modules in the site. In Design Center, students can build a new design scheme, or participate in an existing team by 'Join in Team'. Students can also upload stage results to their Design Center for teachers to check.

- Teacher Group

Teacher Group can also use all the modules, however, the difference is that Teacher Group can download the stage result reports of team members and grade the scheme in Design Center.

3 THE SIGNIFICANCE OF PADUC WEBSITE

The first page must contain the Title, Author(s), Affiliation(s), and Key words. The Introduction must begin immediately below, following the format of this template.

3.1 Significance to Students

PADUC website can be regarded as an offline classroom, which is to supplement the teachers' classroom teaching. When students have a problem, they can ask the teacher in the classroom, but also can publish their questions on the website at any time, to be answered by teachers, experts and other students. Therefore, the website effectively expands the time dimension of students' learning, which is not only limited to classroom time. As the objects of discussion and knowledge sharing are not limited to students and teachers in their own school, but all the members' students, teachers and invited experts, the site effectively helps students to expand their breadth of knowledge. After receiving the design topic, with the previous schemes as a reference, students can have a better understanding of their tasks at each stage. Meanwhile, students can have better judgments on their final achievements. Even better, this website can connect students in different schools to carry out collaborative design. No matter which school students are from, by using the PADUC website, they can complete collaborative design as well as get guidance from their respective teachers. Consequently, the website can enhance communication between students from different schools, and strengthen the teamwork ability of students in the Internet era.

3.2 Significance to Teachers

Prior to the establishment of the site, the scale of students in the 'Aircraft Conceptual Design' course was so large (more than 200 students a semester) that the review of the team design was facing great difficulties. As the large number of students, even if taking the form of group review, it also took up a few times of the classroom time. In addition, due to limited teachers, each review group could only be responsible to several teachers. Nevertheless, every teacher has their own professional direction, so students could gain less professional review direction. Now with the PADUC website, it is not necessary to organize students to review 'Aircraft Conceptual Design' in class. All teachers can conduct a review of the students' work before the prescribed deadline. The advantage is that students can get more opinions from more teachers to recognize the shortcomings of their work and teachers can work flexibly and relieve some work pressure. By browsing the Question & Answer module, teachers can also understand the teaching effect, in order to arrange their next teaching content.

3.3 Significance to Experts

Experts with a wealth of practical experience can assist students to learn more about industrial development and practice methods. In the evaluation stage of the students' design scheme, the experts can present the evaluation from the achievability aspect. At the same time they can give professional solutions to students' questions. Although students did not receive systematic design training, the practical application value of their designs may be relatively small. However, because of their extremely rich imagination and creativity, their designs present more innovativeness and diversity. In the assessment of the design, and exchange with teachers and students, experts are more likely to break with traditional thinking habits in order to get new design inspiration.

3.4 Significance to 'Aircraft Conceptual Design'

The PADUC website currently has five domestic and foreign college allies. By combining with the domestic and foreign colleges in the aerospace courses, members can absorb the teaching advantages each other. Meanwhile, some of the outstanding, cutting-edge design concepts and means can be applied in industry. The universities can learn from each other in the exchange to promote the overall improvement of aerospace design education level.

4 SUMMARY

The PADUC website development is divided into two stages. The first stage is to initiate "Virtual Design Workshop" (VIDEW) based on "Beihang-Purdue Joint Aircraft Design Courses Program". It has given teachers and students of both sides unique and valuable experiences. The second stage is to establish the PADUC website. As a bridge between the member universities and students, the site provides a learning and exchange platform for students, teachers and experts using the website. We do hope that more colleges and universities could join PADUC website, so that lessons learned and experiences gained in separate courses could benefit the improvement of the entire aircraft design education community.

REFERENCES

[1] Hu Liu, Chaoran Wen, Kangwen Sun, Mingqiang Luo,Yaoming Zhou. "From Teamwork to United Courses: Summary of a Decade's Reforms on Undergraduate Aircraft Design Education". 54th AIAA Aerospace Sciences Meeting, 2016.
[2] Lu, P, Liu, H. "Research on web-based educational aircraft design system," 2012 International Conference on Technology and Management, 2012.
[3] Lu, P, Liu, H, Chen, M. Q. "It Will Fly! A New Approach To Web-based Edutainment for Aircraft Design," 50th AIAA Aerospace Sciences Meeting, AIAA 2012-0886, 2012.

[4] Second Life, Software Package, Ver. 3.7, Liden Lab, download URL: http://secondlife.com/support/downloads/ [cited 7 May 2015].
[5] Papadamou, T, Gavrilakis, "Second Life: A Virtual Learning Center for the Study of Sharks," International Journal of Emerging Technologies in Learning, Vol.6, No.2, 2011, pp.19-25.

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USING DESIGN HYPOTHESES IN ENGINEERING STRENGTH AND DESIGN

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Key words: Design Hypotheses, Strength, Engineering.

Abstract. *The work deals with issues related to the use of hypotheses that are convenient for structure design. As a working platform it uses a variation of the super-element model.*

1 INTRODUCTION

The design of any object requires the use of the most objective results of the calculation. It is obvious that at different stages, the design can be done with varying degrees of accuracy. The currently-used advanced technology for aircraft structural design is based on highly accurate mathematical modeling, from the earliest stages of aircraft development. This technology uses scientific achievements related primarily to the successful development of computer technology and numerical methods, such as the finite element method (FEM). This method is the most common and most recognized today. It allows the designer to carry out the analysis and synthesis of structures with a high degree of detail. In aircraft design, FEM has been successfully used for the analysis of structures in various states, including stress-strain conditions (SSC).

However, any detailed calculation requires adequate detail in the preparation of the original data. This is not always possible, especially at the initial design stage. In this regard, the need for relatively simple and operational models of the SSC assessment remains relevant. Primarily this is due to design issues, as there are a huge number of possible design options and a multitude of cases. The task is complicated in the case of significant and non-uniform temperature fields which contribute to the development of phenomena of physical nonlinearity. All of these design situations should be rapidly analyzed.

This process, in which the number of unknowns is always greater than the number of resolving equations is iterative. The tangle of information generated continues to expand the information field of the intended structure, much like the gathering effect on a snowball as it rolls down a snow-covered slope. Obviously, the earlier the design begins to form in the right direction, the better it will turn out in the end. It is also very important that the evaluation uses simple engineering models so that it can be done in less time.

Selecting the right (i.e., grounded) hypotheses plays a major role in the design process as this reduces the number of unknowns significantly. To create a working platform that can function with a variety of hypotheses, a variation of the super-element model is proposed. The term variation in this case indicates that it is possible to vary the number of required movements in the super-element. This is achieved through the use of different hypotheses and assumptions. The proposed model allows a wide range of variation to the order of the system of resolving equations.

2 ENGINEERING DESIGN MODEL

The main, thin-walled load-bearing elements such as the wings, tail, and fuselage (Fig. 1) that are in a uniaxial SSC, are divided into one-dimensional elements and two-dimensional elements (membrane). A calculation model, which describes the design work, can be drawn from these elements. This consists of the skin and different types of core elements: longitudinal (stringers, longitudinal walls, spars, beams, panels) and transverse (ribs, frames). The task analysis of the SSC is solved in displacements, where $\boldsymbol{u}$ (u_x, u_y, u_z) is the displacement vector at any point of the structure.

The design is divided along the longitudinal axis z with an arbitrary step (better if they coincide with the transverse force elements) on the c substructures – super-elements (Fig 1, *b*.).

As a result, the estimated model design will consist of: n-longitudinal ribs; m-flat membrane panels; and c-transverse elements (the zero element is a plane structure seal).

The desired movements are represented as the product of generalized displacement (**Φ**) and approximating functions (***T***), which can be considered as generalized coordinates $\boldsymbol{u}=\boldsymbol{T\Phi}$ This approach resembles the representation of fluctuations, both in form and in frequency. (1)

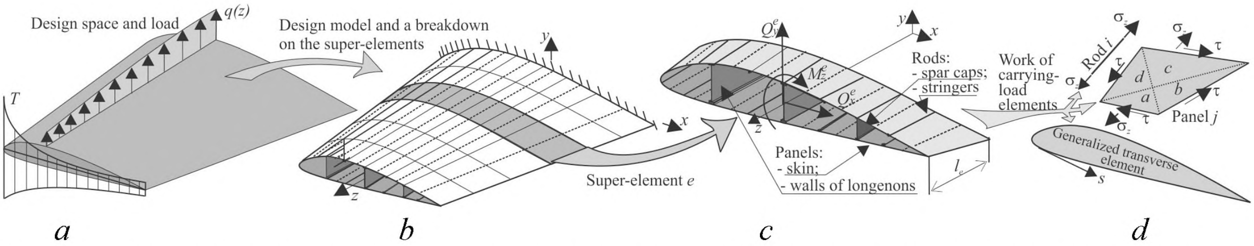


Figure 1: The projected construction: *a*-external contours and operating mechanical and thermal load; *b*– load-bearing scheme and a segment of the regular domain decomposition is considered; *c*–structure of super-element; *d*-calculation model of load-bearing elements

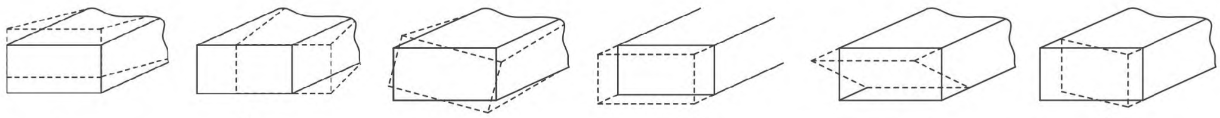
Thus, each section is a calculated synthesis unit which has M degrees of freedom in the transverse and N – longitudinally. Each compartment essentially becomes a super-element with generalized movements in the super-nodes that are limited to that compartment.

The movement of the intersection point of e and e+1 section in such a variant of a super-element can be expressed in generalized displacements in these sections.

$$\begin{bmatrix} \boldsymbol{u}^e \\ \boldsymbol{u}^{e+1} \end{bmatrix} = \begin{bmatrix} \boldsymbol{T}_1^e & \boldsymbol{T}_2^e & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{T}_1^{e+1} & \boldsymbol{T}_2^{e+1} \end{bmatrix} \begin{bmatrix} \boldsymbol{\varphi}^e \\ \boldsymbol{\psi}^e \\ \boldsymbol{\varphi}^{e+1} \\ \boldsymbol{\psi}^{e+1} \end{bmatrix} \tag{2}$$

where φ_e and φ_{e+1} are vectors of generalized displacement $\{\varphi_1, \varphi_2, \ldots, \varphi_M\}$ that lying in the plane of the cross-sections e and e+1; ψ_e and ψ_{e+1} are vectors of generalized displacement $\{\psi_1, \psi_2, \ldots, \psi_N\}$, directed out of the plane of cross-sections; T_1 and T_2 are corresponding transformation matrix (approximating function) in transverse and longitudinal directions. It is selectable depending on the various hypotheses (classical beams theory, taking into account warping and sectional contour deformation at different levels of accuracy). This approach allows the designer to obtain solutions with varying degrees of accuracy, and thus the complexity of the process of analysis will be reduced.

The simplest version of the proposed calculation model is $M = 3$ (hard circuit hypothesis) and $N = 3$ (beam design work design section). Fig. 2 shows an approximation function for this decision.



a *b* *c* *d* *e* *f*

Figure 2: The simplest approximation of displacements
a–c – in a transverse direction; *d–f* – in a longitudinally direction

In the early stages of design or in the evaluation of new operational capabilities, the super-structure model may be more effective. The super-structure occupies an intermediate status between the beam and the classic FEM – i.e. with greater capacity than the simplest beam model, but less cumbersome than FEM.

The basis of this model is the super-element variation, which can be used in combination with various traditional design hypotheses. The word "variation" in this term means the variability of computational accuracy, ranging from the beam to maximum in the model.

Let us analyze the variation engineering design model from an energy point of view. In order to simulate the stress-strain condition (SSC), the super-elements are divided into three groups: the longitudinal ribs, panels and transverse elements (Fig. 1, *c*). Thus the work done by the existing external load turns into potential energy of deformation of these elements:

$$A \Rightarrow U = U_{LR} + U_P + U_{CR} \qquad (3)$$

where U_{LR}, U_P, U_{CR} are, respectively, potential energy of: longitudinal rods, panels and transverse elements.

When considering only the first component in the equation (3) is obtained by the simplest solution - known as beams in the Euler-Bernoulli version.

$$U \approx U_{LR} \qquad (4)$$

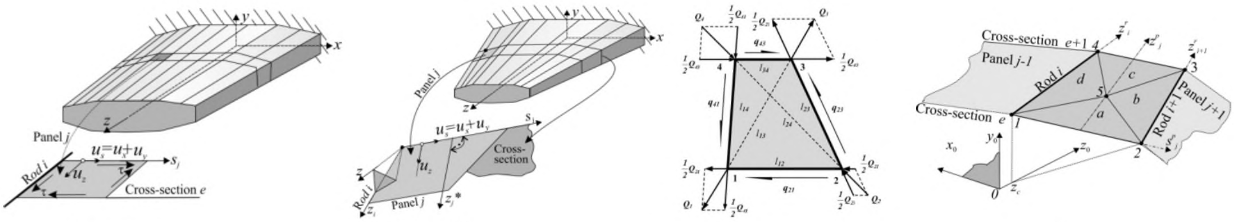
This solution can be adjusted taking into account the transverse shear (beam Tymoshenko type).

The task is greatly simplified if the assumption of absolute rigidity of the cross-sections is adopted, as in this paper. This hypothesis was widely used in design practice during the period of 1940s-1970s. Using this hypothesis implies that in formula (1) there is no third term

$$U \approx U_{LR} + U_P, \quad (U_{CR} = 0) \qquad (5)$$

The stiffness matrix of the longitudinal rods has the simplest form.

The most difficult structure to assess using this model is the operational panel. It is easy to do in cylindrical structures – Fig.3, *a* [1, 2]. Various computational circuit boards may be applied to account for taper, as shown in Fig. 3, *b*, *c*. The most comprehensive is the traditional finite element scheme of the panel, as the isoperimetric quadrilateral element or the use of four triangular elements with the exception of the central node – Fig. 3, *d* [3].



a *b* *c* *d*

Figure 3: Schema of panel working: *a* – cylindrical, on shear; b – slightly conical, on shear; *c* – conical on shear; *d* – conical with normal and shear stress

The most convenient for design work is an option with a shell that works only on shear, and with a hard cross-sectional contour (Fig.4). In the latter case, it does not require information on the cross-power components, which greatly simplifies the solution of the problem, while maintaining sufficiently high accuracy.

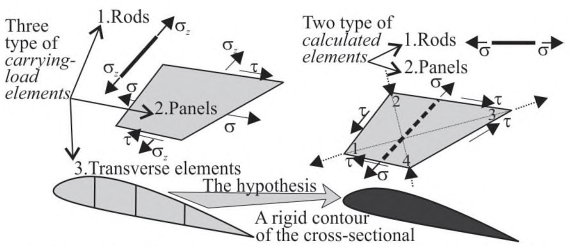


Figure 4: Work of main carrying-load elements with using hypothesis of absolutely rigidity contour of the cross-section

The use of design hypothesis is not only of scientific value, but also has great value in terms of methodology. Students are given a lot of time to study the theoretical foundations of FEM, and software products that are based on this method. However, considerable user skills are required to work effectively with these software programs and students don't generally have the time to focus on enhancing their knowledge of them in order to understand the subtleties of FEM, and hence gain maximum advantage from them. So, in order to make the development process more profound for the students, the use of design hypotheses will allow them to better understand the physics of the process, thus they become more adequately prepared to address the problems of non-standard design.

The initial problem for the implementation of such an approach is also the easiest to solve - the student must make a structural analysis program based on the beam model. It is best to start with the Euler-Lagrange beams. Next, consider the influence of shear (Timoshenko beam) as well as the effect of warping, by using the hard-circuit hypothesis. Thirdly, consider the effect of the deformation contour of the cross sections. The most suitable software environment for small order equations is MATLAB. Next, they need to make a comparison of simple examples of classical solutions by FEM and the design of an engineering model using different hypotheses. Such an analysis makes it easier to understand the design operation and to realize its influence over the main elements of the design parameters.

Numerous computational studies have shown good correlation between the results obtained by the proposed model with the results of experiments and using traditional FEM.

3 CONCLUSIONS

1. Experience of use of various engineering hypotheses on the basis of the developed model showed an acceptable accuracy of the results and its ease for use for the early stages of design.
2. This calculation model with a variety of hypotheses allows occupying a wide engineering niche between the traditional beam model and the classical FEM
3. The use of this methodology in the educational process has confirmed its methodological value for students to gain in-depth understanding of the design methods.

REFERENCES

[1] Wang Z., Huang S., Kretov A., Kang L. Thermo strength Designing model thin-walled structures. Vestnik KNRTU-KAI. Kazan. 1, 93-103, 2015 (In Russian).

[2] Wang Z., Huang S., Kretov A., Kang L. Designing model of strength of thin-walled structures. Aviation technique. 1, 116-122, 2016 (In Russian).

[3] Huang S. Evaluation of engineering design aircraft models with a variety of options for addressing the taper. Vestnik KNRTU-KAI. Kazan. 6, 92-101, 2015 (In Russian).

ASIAN
WORKSHOP ON AIRCRAFT DESIGN EDUCATION

PHOTO GALLERY

FROM THE FIRST AWADE SEMINAR

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第一届亚洲飞机设计教育研讨会·2016
The 1st Seminar of the Asian Workshop on Aircraft Design Education
AWADE 2016
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Chinese Society of Aeronautics and Astronautics
October 08-11 , 2016
Nanjing China
航空宇航学院
College of Aerospace Engineering


The 1st Seminar of Asian Workshop on Aircraft Design Education (AWADE)
NUAA, Nanjing, October 08-11 2016
AsianWADE
The Participants of the 1st AWADE Seminar

Director of Int. Coop. Office NUAA
Prof. *Quanyuan Jin* and
Prof. *Xiongqing Yu* and
Prof. *Rajkumar S. Pant*
discussing the program
the AWADE Seminar

Anthony P. Hays is preparing
to lead the session

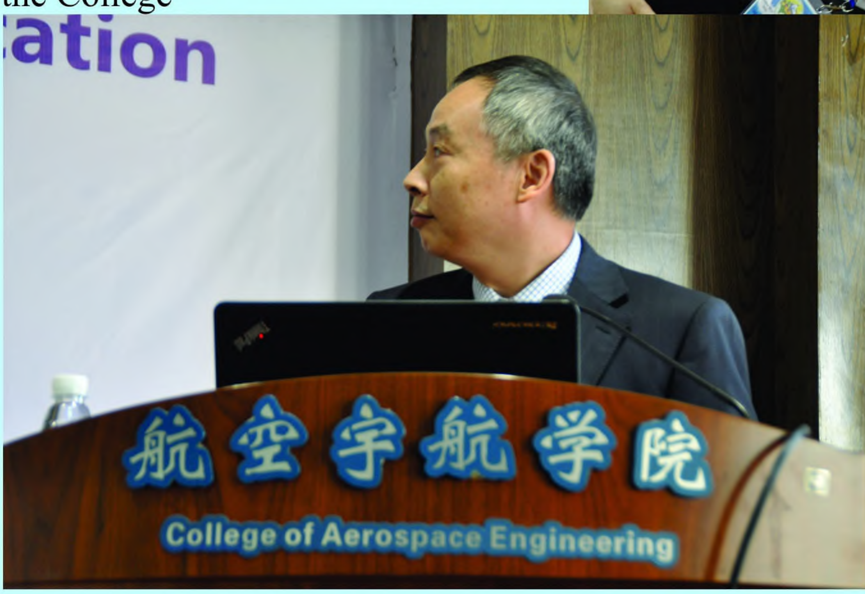
Getting to know you:
Acct.Prof. *Oleksiy Chernykh*
with Prof. *Xiongqing Yu*

Seminar
Audience

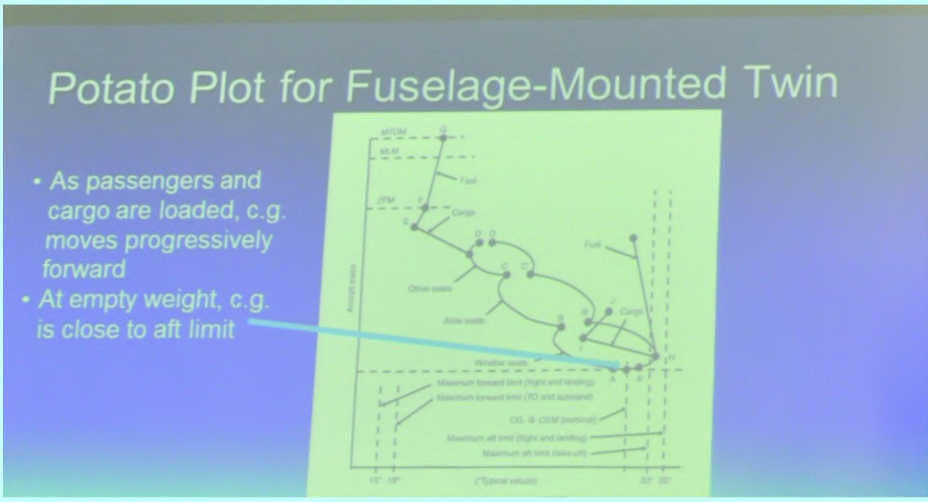
Director of Int. Coop. Office
NUAA Prof. *Quanyuan Jin*
welcomes the participants
in his speech to open
proceedings

Participants from Russia
Elena Gernshtein and
Prof.Valentin Khaliulin

Dean of Aerospace
Engineering College NUAA
Prof. *Pinqi Xia* explains the
structure of the University and
the College



Prof. Anatolii Kretov
introduces the history
of EWADE: the European
counterpart to AWADE

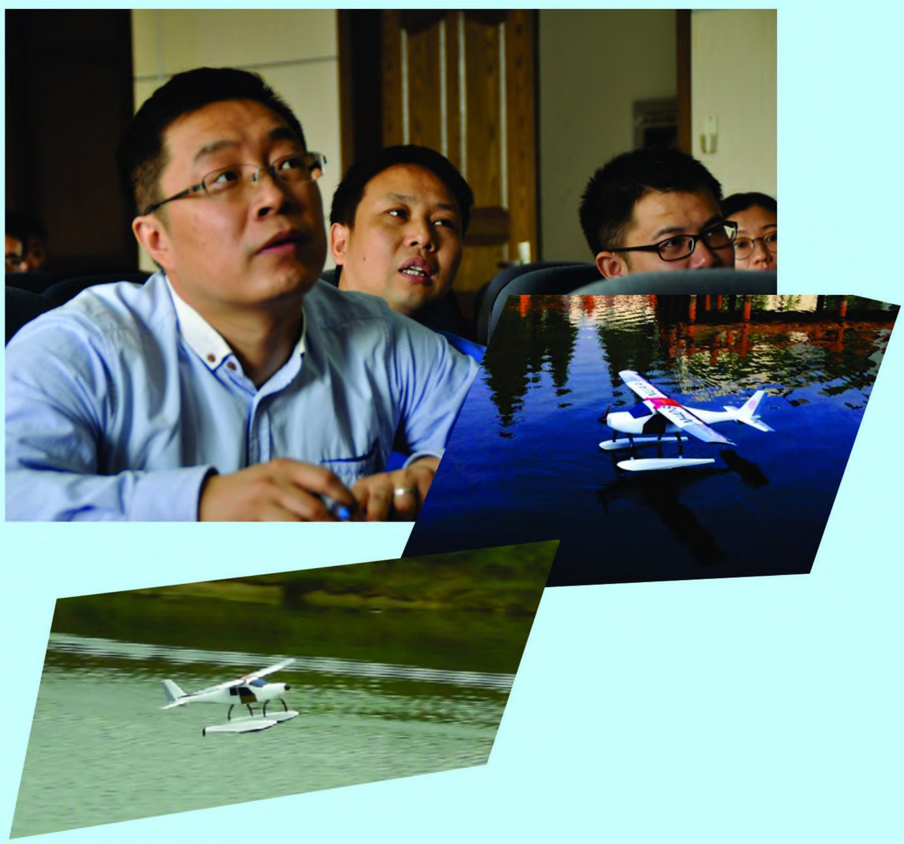


The presentation of an experienced designer *Anthony P. Hays*
Teaching Aircraft Conceptual Design at the Undergraduate and Graduate Levels

The presentation of Prof.*Xiongqing Yu*

The Electric Powered UAV design//Build/Fly Project for Undergraduates at NUAA

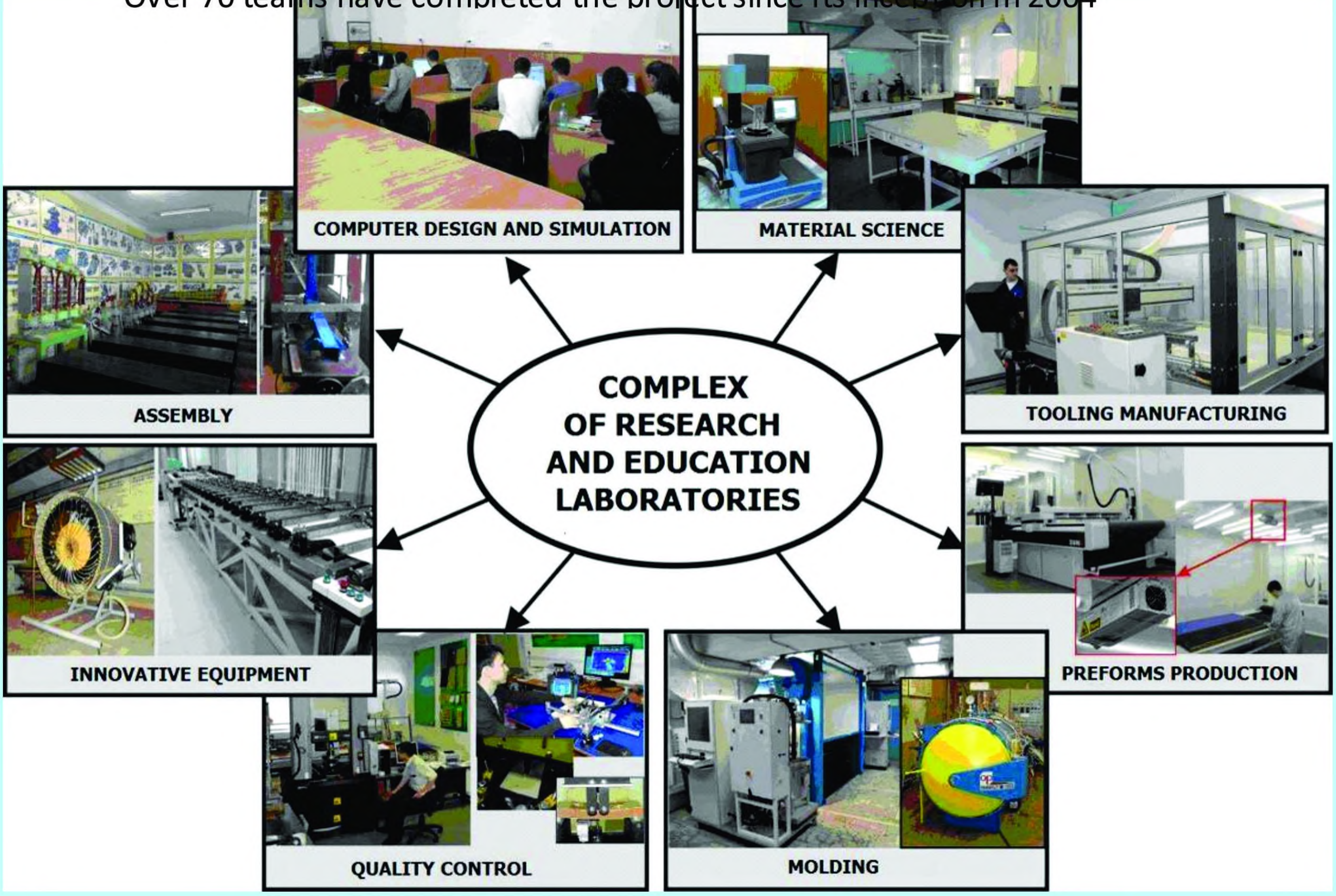
Over 70 teams have completed the project since its inception in 2004



Prof.Valentin Khaliulin and *Elena Gershtein*

A Complex of Laboratories for Practical Training of Students in Composite

Over 70 teams have completed the project since its inception in 2004



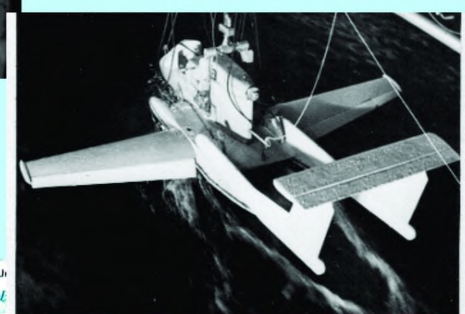
Let's raise AWADE to a decent standard

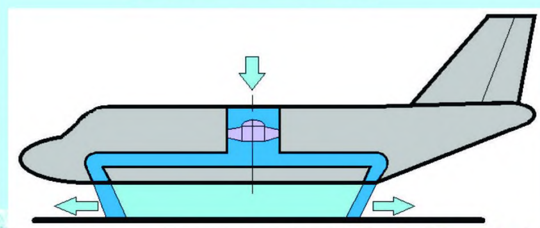
Prof.Rajkumar S. Pant

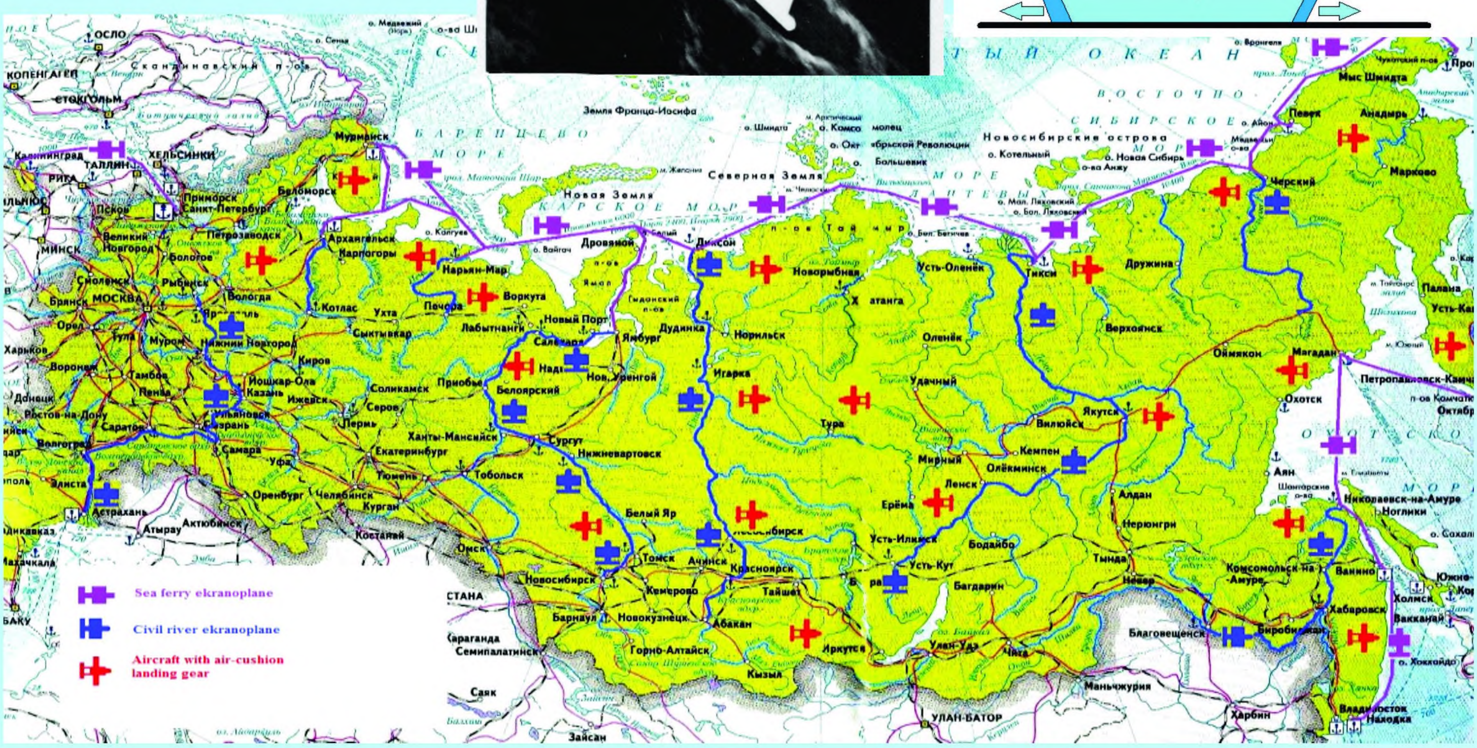
Design-Build-Fly Projects of Lighter-Than-Air Systems for Enhanced Learning of Aircraft Design Principles

Morozov's Aircraft DINGO

Prof.Victor Morozov
Transport efficiency of aircraft with air-cushion landing gear



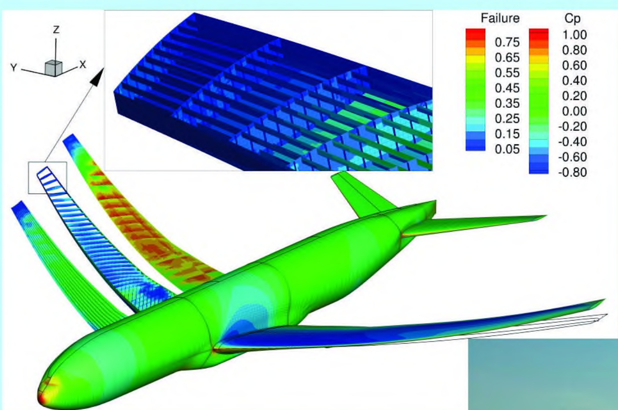




Amphibious transport network in Russia

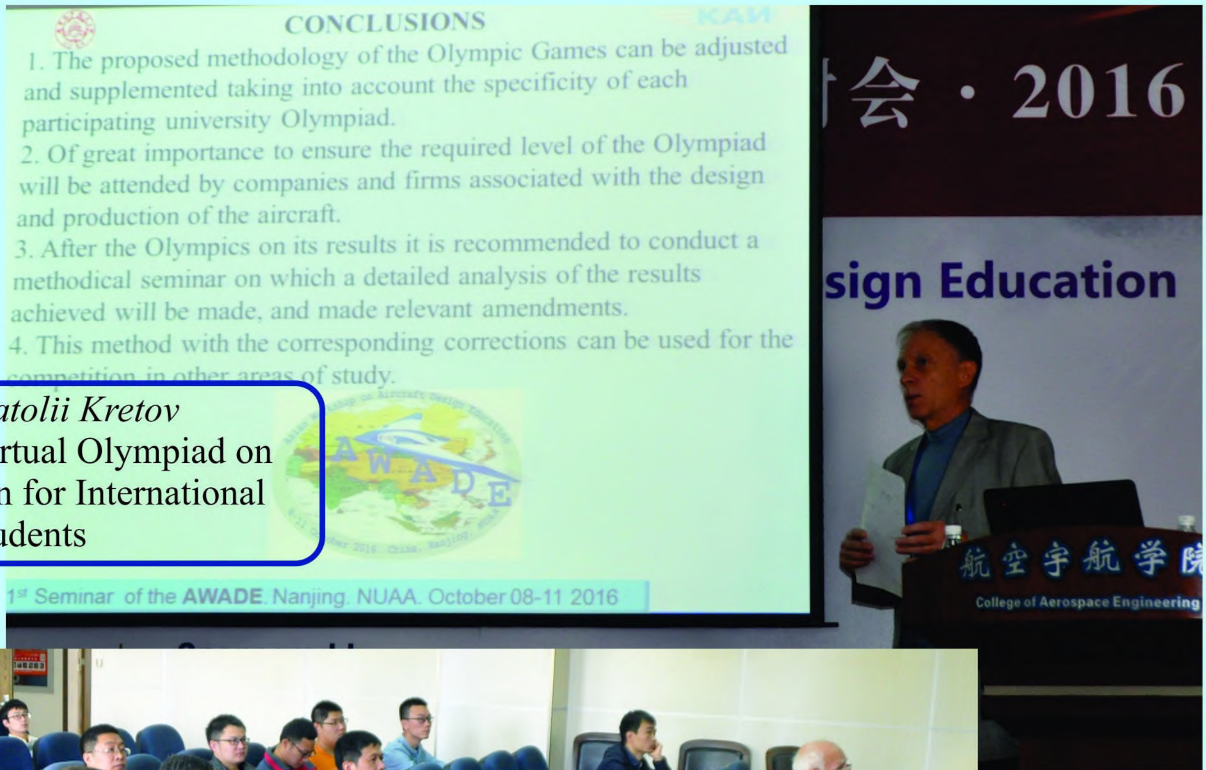
Rhea P. Liem

Modern Aircraft Design Goes Beyond the Classical Aerospace Engineering

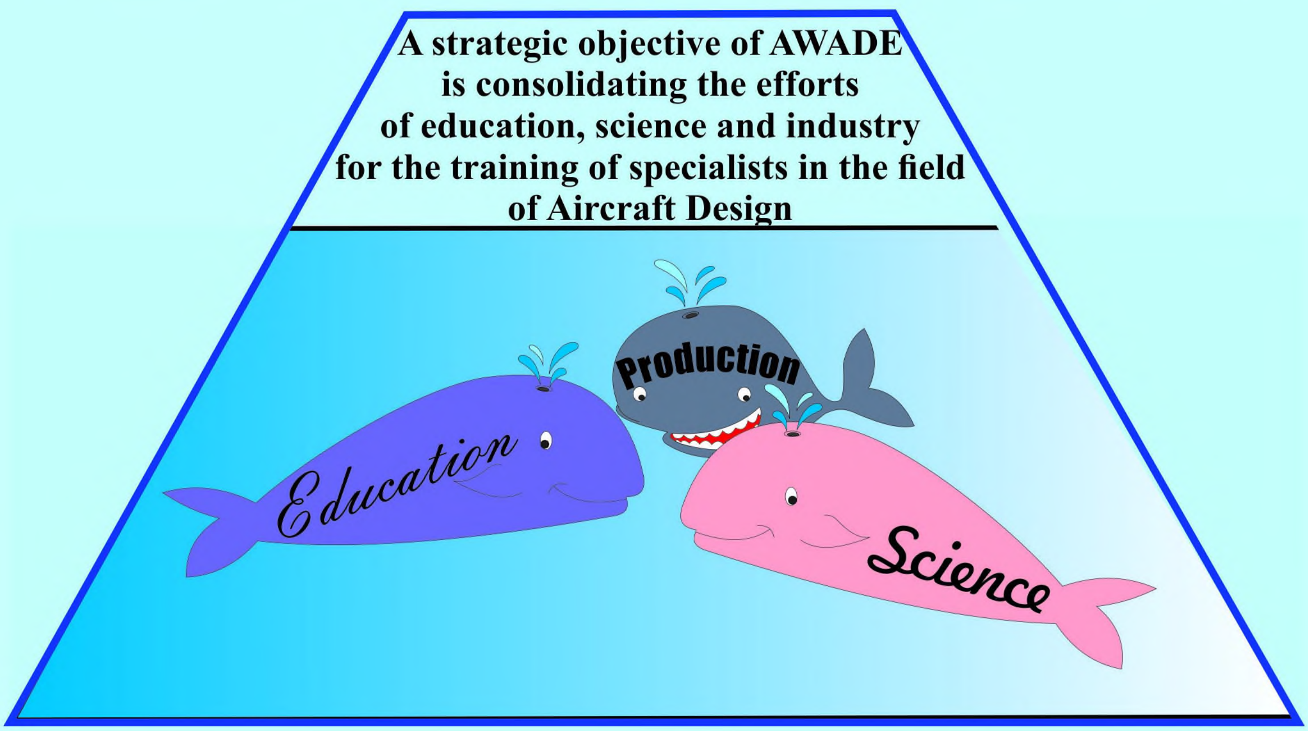


Clifton Read and Anatolii Kretov
Aircraft Design: Real Life Examples in Education

The discussion continued during the coffee break



Prof.Anatolii Kretov
outlines the Virtual Olympiad on Aircraft Design for International Students



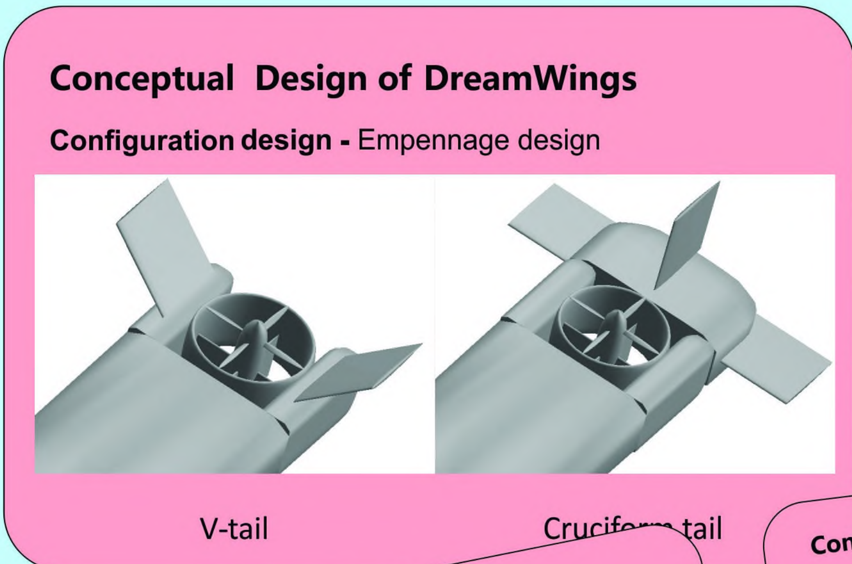
Oleksiy Chernykh

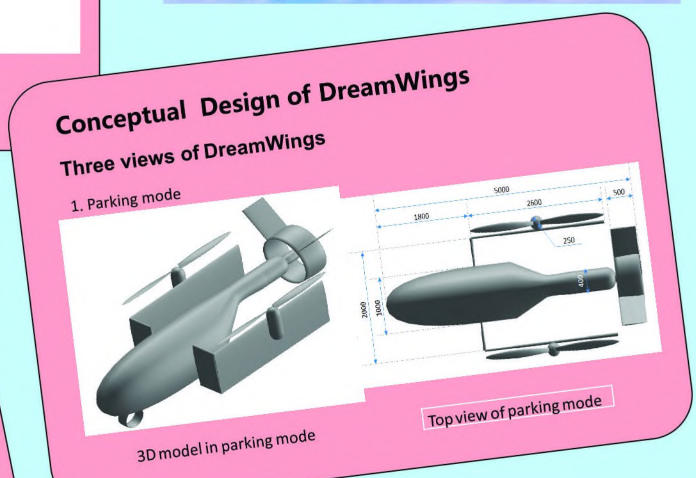
Learning of Russian Aviation Regulations by Chinese and International Students

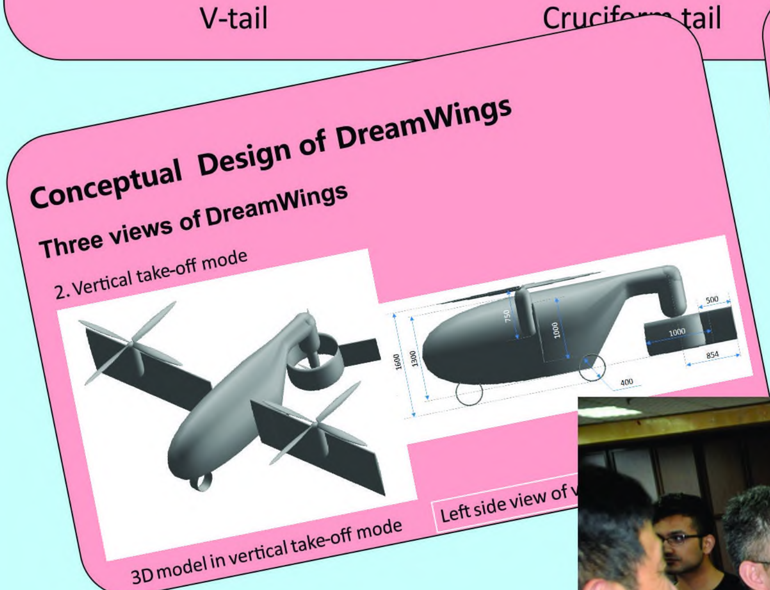
Historical Questions are always interesting for all audiences

Preliminary Design of VTOL Personal Flying Machine - DreamWings

Jiajie Luo, Bohan Du, Wenbin Song
School of Aeronautics and Astronautics
Shanghai Jiao Tong University







Conceptual design of submersible aircraft with morphing technology

Tutor: Wenbin Song
Team members: Zetian Zhang, Huiming Cai, Xin Wang

Background

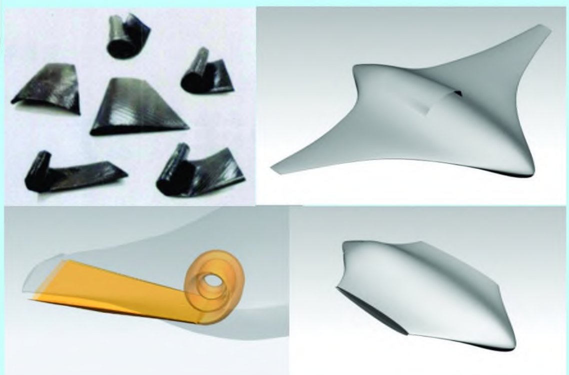
Nowadays UAVs (Unmanned Aerial Vehicles) are gradually taking more places of manned aircraft because of its high flexibility, security and low -cost. UAVs are often preferred for missions that are too "dull, dirty or dangerous" for humans

UAV's advantages

1, Security
2, Low-cost
3, high flexibility

UAV's developing trends

1, High maneuverability
2, stealth
3, large combat radius



Background

A submersible aircraft capable of water takeoff and landing is a combination of a seaplane and an underwater vehicle.
It can be launched from a submarine and can cruise under water to striking distance, all without alerting defenses.
It is supposed to be able to fly as well as to cruise under water.

Drawn by Zhang Zetian, Shen Jiaying

Advantages of the submersible aircraft

(1) the speed and range of an aircraft
(2) the voyage abilities of a boat
(3) the stealth of an underwater vehicle

Thank you for your attention!

谢谢

Any Questions?


Asian Workshop on Aircraft Design Education
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Discussion on possible future action of the AWADE


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Others
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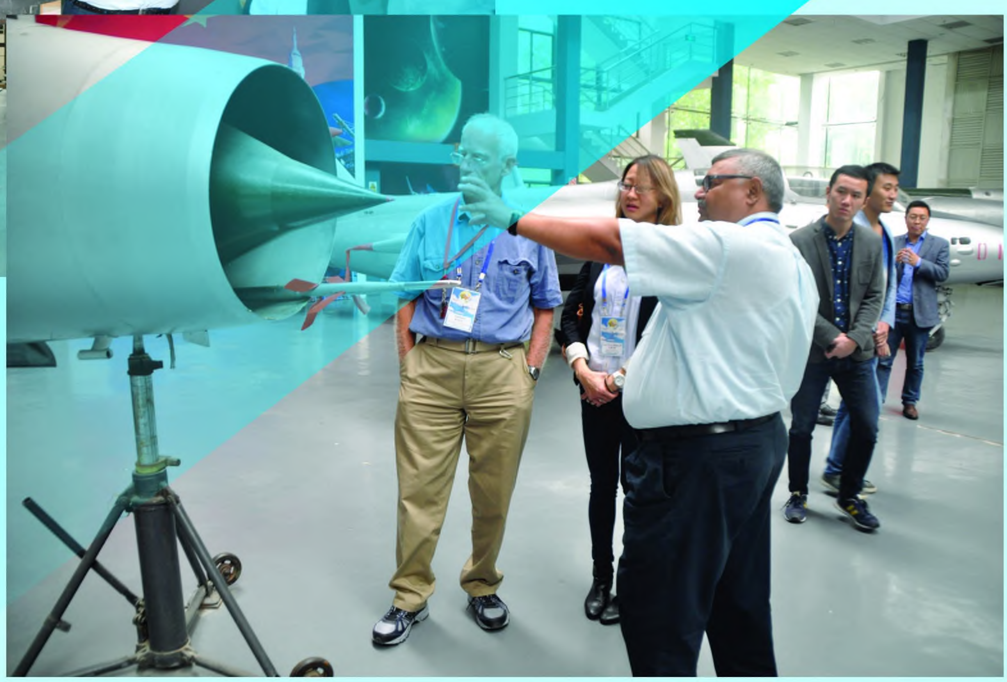
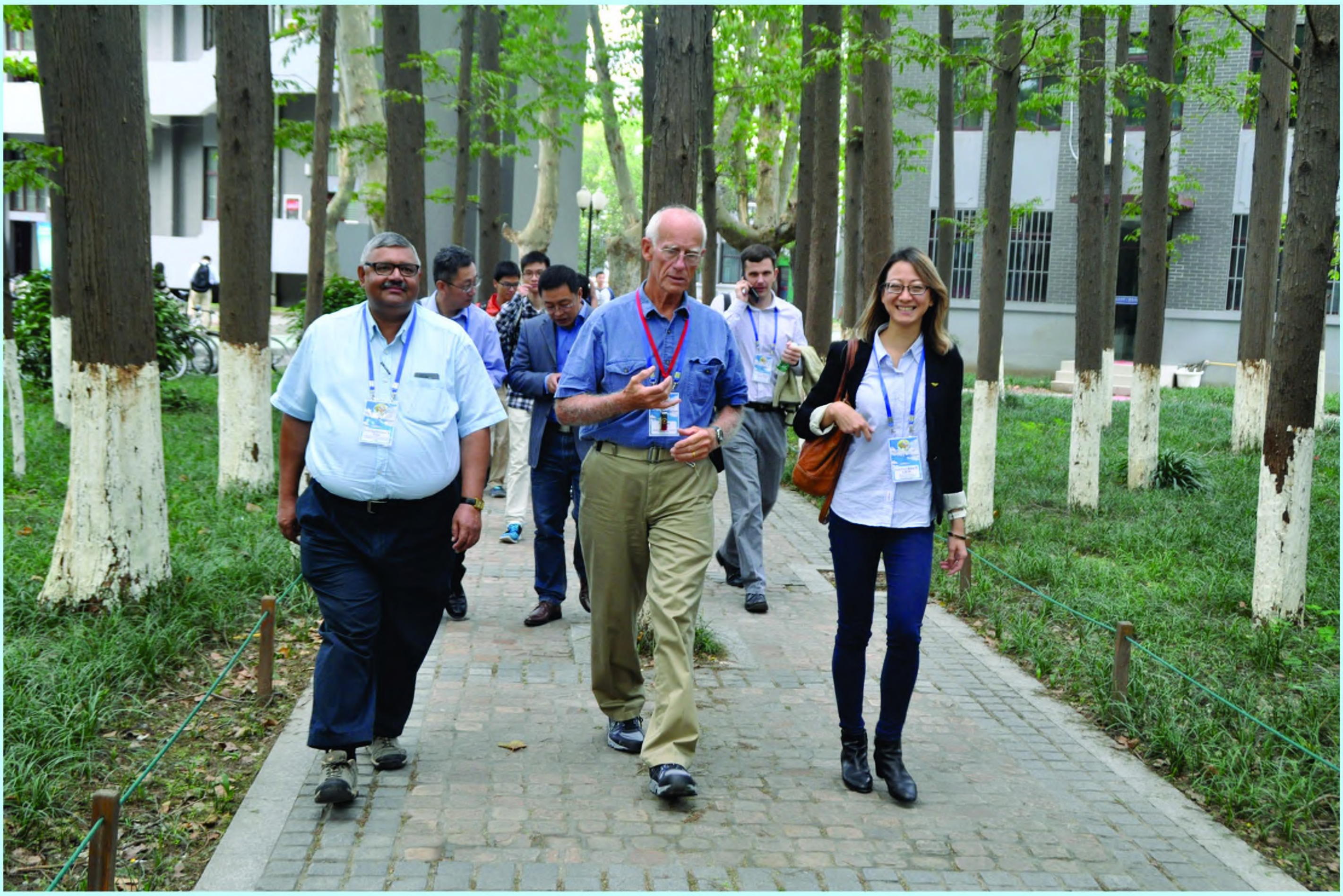
Internships
The joint student projects
Joint publication of methodical literature
Exchange teachers
Exchange students

Aviation Museum Visit



Aviation Museum Visit



Business before pleasure


PROCEEDING
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GREETINGS

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WITH TYPICAL "EWADE-SPIRIT", WE WISH YOU PLEASANT DAYS.

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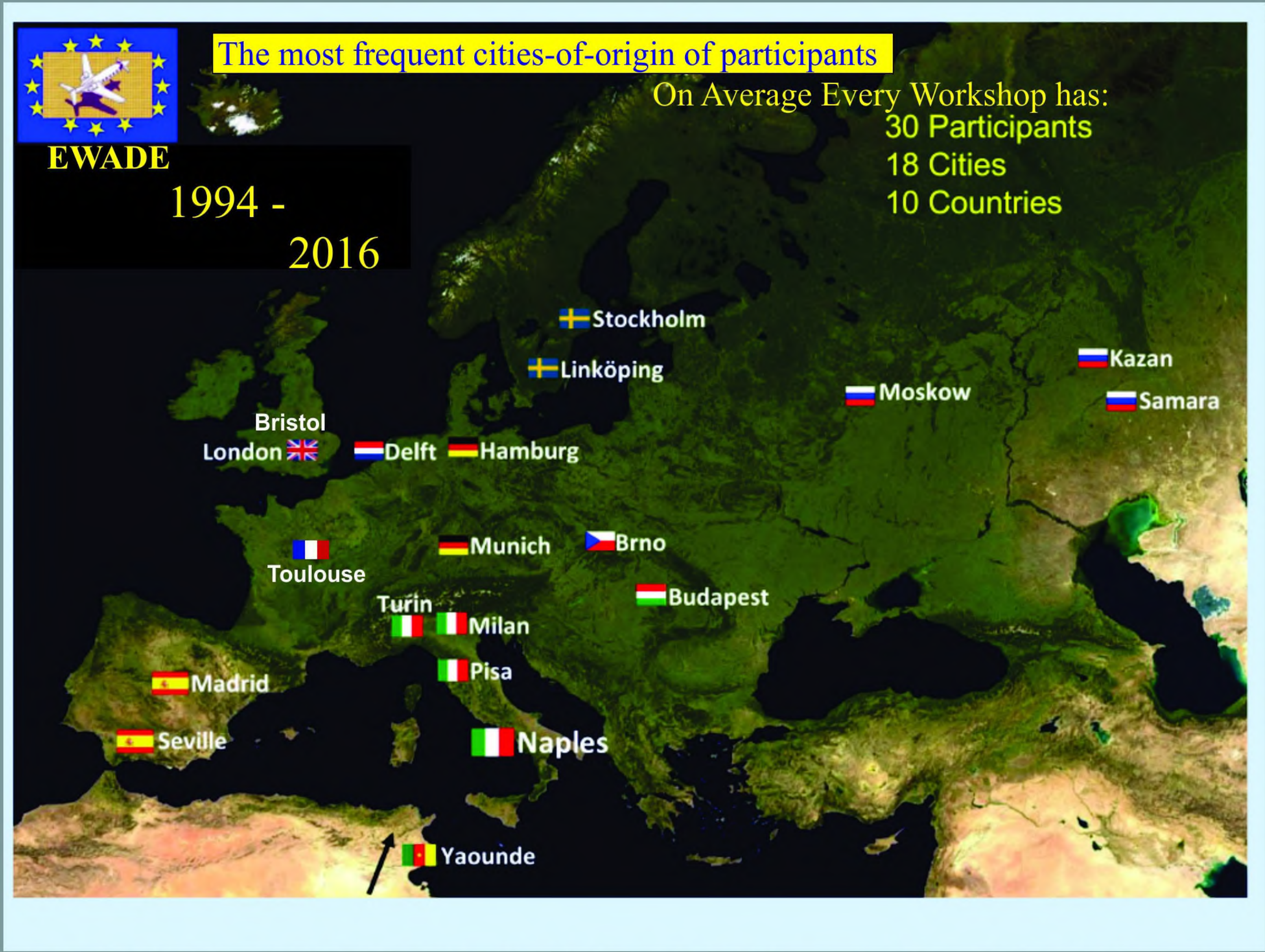

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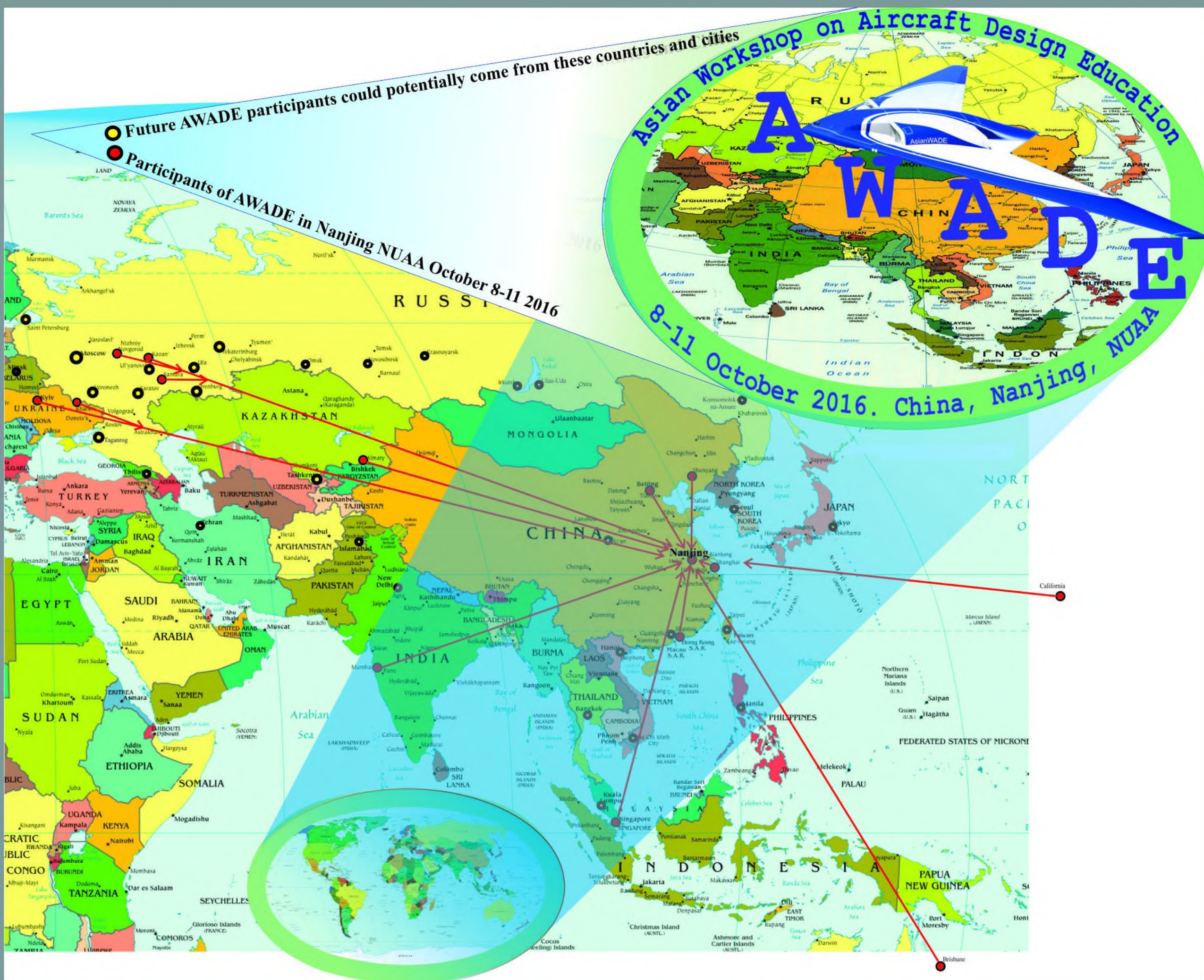


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