

LETALSKI MOTORJI 2

UČNI NAČRT PREDMETA/COURSE SYLLABUS

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| Predmet: | Letalski motorji 2 |
| Course title: | Aircraft engines 2 |
| Članica nosilka/UL Member: | UL FS |

| Študijski programi in stopnja | Študijska smer | Letnik | Semestri | Izbirnost |
|-----------------------------------------------------------------------------------|-------------------------------------------|-----------|-------------|-----------|
| Strojništvo - projektno aplikativni program, prva stopnja, visokošolski strokovni | Prometni pilot letala/helikopterja (smer) | 3. letnik | 1. semester | obvezna |
| Strojništvo - projektno aplikativni program, prva stopnja, visokošolski strokovni | Snovanje in vzdrževanje letal (smer) | 3. letnik | 1. semester | obvezna |

Univerzitetna koda predmeta/University course code: 0564001

Koda učne enote na članici/UL Member course code: 3085-V

| Predavanja /Lectures | Seminar /Seminar | Vaje /Tutorials | Klinične vaje /Clinical tutorials | Druge oblike študija /Other forms of study | Samostojno delo /Individual student work | ECTS |
|-------------------------|---------------------|--------------------|--------------------------------------|-----------------------------------------------|---------------------------------------------|------|
| 30 | | 30 | | | 65 | 5 |

Nosilec predmeta/Lecturer: Tomaž Katrašnik

Vrsta predmeta/Course type: Izbirni strokovni predmet /Elective specialised course

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| Jeziki/Languages: | Predavanja/Lectures: | Slovenščina |
| | Vaje/Tutorial: | Slovenščina |

**Pogoji za vključitev v delo oz. za
opravljanje študijskih obveznosti:**

Izpolnjevanje pogojev za vpis v
Visokošolski strokovni študijski program
I. stopnje Strojništvo - Projektno
aplikativni program.

Prerequisites:

Meeting the enrollment conditions for
the MECHANICAL ENGINEERING -
Project Oriented Applied Programme.

Vsebina:

1. Osnove turbinskih motorjev
- Razvrstitev turbinskih motorjev.
- Pretvorbe energije, potek
termodinamskega procesa, potek
temperatur, tlakov in hitrosti delovne
snovi.
- Potisna sila, moč potisne sile, notranji
in zunanji izkoristek, specifična poraba
goriva.
2. Vrste turbinskih motorjev
- Razdelitev glede na uporabo, ciljno
hitrost, zanesljivost in specifično porabo
goriva.
- Razlike in razlogi za uvedbo
enotokovnih, turboventilatorskih,
turbopropelerskih, turbogrednih
motorjev.
- Sistematizacija komponent: vstopniki,
kompresor, zgorevalna komora, turbina,
izpušni sistemi.
3. Vstopniki in difuzorji
- Definicije in vloga totalne temperature,
totalnega tlaka, odlepljanja toka v
vstopnikih in difuzorjih.
- Podzvočna in nadzvočna geometrija
vstopnikov, potek parametrov v
konvergentno-divergentni šobi.
- Poškodbe, preprečevanje zaledenitve,
vpliv smeri natoka in smeri leta, vpliv
turbulence.
- Posebne izvedbe vstopnikov.
4. Aksialni in radialni kompresorji 1
- Potek parametrov, oblike lopatic,
termo-mehanske obremenitve, materiali,
vloga ventilatorja.
- Delovno območje, vpliv vrtilne
frekvence temperature in tlaka na
konstrukcijske rešitve.
- Delovno območje, potek tlačnih izgub,
meja stabilnega delovanja, zamašitev

Content (Syllabus outline):

1. Turbine engine basics
- Classification of turbine engines.
- Energy conversions, turbine engine
thermodynamic parameters in terms of
temperature, pressure, velocities of the
working medium.
- Thrust, Thrust power, thermal
efficiency, propulsive efficiency, specific
fuel consumption.
2. Turbine engine types
- Categorization according to use, target
aircraft velocity, reliability and specific
fuel consumption.
- Comparative analysis and use cases of
turbojet, turbofan, turboprop and
turboshaft engines.
- Overview of components: engine inlets,
compressor, combustion chamber,
turbine, nozzles.
3. Aircraft engine inlets and diffusers:
- Definition and role of total
temperature, total pressure, flow
separation in inlets and diffusers.
- Subsonic and supersonic inlet
geometry, flow parameters in
convergent-divergent nozzles.
- Engine inlet damage, de-icing, impact
of flow uniformity, turbulence effects.
- Application-specific engine inlets.
4. Axial and centrifugal compressors 1
- Thermodynamic parameters along the
air path, blade shape, thermo-mechanic
loads, materials, role of fan.
- Compressor performance map, impact
of rotational velocity, temperatures and
pressures on compressor design.
- Compressor performance map,
associated pressure losses, stall line,
surge line.

toka.

- Enogredna in večgredna zasnova, uvedba variabilne geometrije lopatic.

5. Aksialni in radialni kompresorji 2

- Aksialnimi in radialnimi kompresorji: razlike, prednosti in slabosti ter področja uporabe posamezne izvedbe.
- Tlačna razmerja, določitev oblike rotorja, primeri kombiniranih izvedb.
- Dobava komprimiranega zraka, zasnova ventilov za uravnavanje tlaka.

6. Zgorevalne komore 1

- Pretvorba energije, dovod toplote, topologija motorja in povezane vrste zgorevalnih komor, trendi razvoja zgorevalnih komor.
- Primeri zgorevalnih komor, načini vgradnje, področja uporabe in konstrukcijske značilnosti, materiali.

7. Zgorevalne komore 2

- Osnove zgorevanja, delitev zračnega toka, temperaturni in koncentracijski profili delovne snovi.
- Pristopi za zmanjševanje izpustov onesnažil, napredne oblike zgorevalnih komor.
- Značilne poškodbe zgorevalnih komor, vzroki, diagnostika poškodb.
- Vrste vbrizgovalnih šob, osnove razpada curka, omejitve pri spreminjanju moči motorja.

8. Turbine

- Vloga turbine v različnih vrstah turbinskih motorjev, uvedba večstopenjske turbine, eno in večgredne izvedbe, aksialne in radialne izvedbe.
- Impulzna, reakcijska turbina, stopnja reaktivnosti, karakteristika aksialne in radialne turbine.
- Termo-mehanske omejitve, temperaturni profili, hlajenje lopatic, uporabljeni materiali z omejitvami.
- Vpliv puščanja na izkoristek motorja, tesnjenje, spreminjanje dimenzije špranje med letom.
- Poškodbe turbine, diagnostika poškodb, tipi konstrukcije.

9. Izpušni sistemi

- Razvrstitev in vloga izpušnih kanalov,

- Single shaft and multi-shaft design, role of variable stator blades.

5. Axial and centrifugal compressors 2

- Comparative analysis: differences, advantages, drawbacks and specific applications.
- Pressure ratios, rotor geometry design, combined axial and centrifugal compressors.
- Bleed air supply system, bleed valve design and operation.

6. Combustion chambers 1

- Energy conversion pathways, heat supply, engine topology and suitable combustion chamber types, development trends.
- Examples of combustion chambers, installation methods, areas of use, construction specifics, materials.

7. Combustion chambers 2

- Basic combustion principles, airflow division and routing, temperature and concentration profiles of the working medium.
- Approaches for emission reduction, advanced combustion chamber design.
- Common faults, causes and fault diagnostics.
- Fuel injection nozzles, spray break-up principles, limitations in power modulation.

8. Turbines

- Role of turbine in different aircraft engine types, introduction of multi-stage and multi-shaft turbines.
- Impulse and reaction turbine, degree of reaction, characteristics of axial and radial turbines.
- Thermo-mechanic limitations, blade temperature profiles, blade cooling, applicable materials and their limitations.
- Blade tip sealing and impact on specific fuel consumption, active and passive sealing systems.
- Blade faults, blade design and fault diagnostics.

9. Exhaust and exhaust nozzles.

- Classification and role of exhaust, exhaust nozzles and thrust reverse.

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| <p>potisnih šob in obračalnikov potiska.</p> <ul style="list-style-type: none"> - Oblike potisnih šob in potisne šobe s spremenljivo geometrijo, tipi aktuatorjev, potek potisne sile v odvisnosti od geometrije. - Naknadno zgorevanje v izpušnem kanalu, potek termodinamskih parametrov, omejitve, uporabnost, vpliv na specifično porabo goriva. - Načini merjenja temperature v izpušnem kanalu, pomen za potrebe krmiljenja in diagnostike motorja. <p>10. Obračalniki potiska in hrup</p> <ul style="list-style-type: none"> - Tipi obračalnikov potiska za različna obvodna razmerja, konstrukcijske rešitve za preusmerjanje obvodnega zraka in skupnih potisnih plinov. - Strategija uporabe, varnostni krmilni mehanizmi, pogoji pri katerih se obračalniki potiska uporabljajo, vpliv povratnega toka na poškodbe vstopnika in kompresorja. - Obračalniki potiska pri turbopropellerskih motorjih. - Viri hrupa turbinskih motorjev in pristopi za zmanjševanje v radialni in aksialni smeri, značilne frekvence in viri posameznih spektrov. <p>11. Sistemi za dobavo goriva in mazanje motorja</p> <ul style="list-style-type: none"> - Goriva za turbinske motorje, krovni standardi, trendi v razvoju goriv, kompatibilnost standardov in ključne kemijsko-fizikalne lastnosti. - Komponente gorivnih sistemov in njihova funkcija. - Shematski prikaz sistema s krmilnimi parametri in krmilno enoto za gorivo. - Vrste črpalk za gorivo in zagotavljanje redundance. - Sistem za mazanje motorja s konstantnim tlakom, dobavljanje mazalnega sredstva do komponent, pogon in vloge različnih črpalk. - Oljni filtri, zaznavanje kontaminantov, omejitve uporabljenih maziv, hlajenje. <p>12. Zagon motorja</p> <ul style="list-style-type: none"> - Sestavni deli vžigalnega sistema in delovanje, - Klasifikacija zaganjalnikov z ozirom na | <ul style="list-style-type: none"> - Exhaust nozzle types, variable nozzle geometry, actuator types, impact of nozzle geometry on thrust. - Afterburners, impact on thermodynamic parameters, performance and specific fuel consumption, limitations, applicability to different engine types. - Temperature measurements in exhaust, impact on control strategies and diagnostics. <p>10. Thrust reverse</p> <ul style="list-style-type: none"> - Thrust reverse types, selection according to different bypass ratios with design specifics for each type. - Use of thrust reverse, safety limitations, enabling conditions, impact of reversed flow on engine damage. - Thrust reverse with turbo-propeller engines. - Engine noise and principles for minimization in axial and radial direction, characteristic frequencies and origins of emitted spectra. <p>11. Fuel supply and lubrication systems.</p> <ul style="list-style-type: none"> - Aircraft engine fuels, governing standards, fuel development trends, compatibility of standards, key physical and chemical properties. - Fuel supply system components and their role. - Schematic diagrams of fuel supply systems with key parameters and fuel control unit. - Fuel supply pumps and redundancy. - Lubrication systems with constant pressure, oil supply to key engine components, pump types and pump drives. - Oil filters, oil quality sensors, limitations for different lubricants, cooling circuits. <p>12. Engine start-up</p> <ul style="list-style-type: none"> - Ignition systems structure and operation. - Engine starters for different engine types and use. - Engine start-up on ground and in flight for airplane and helicopter engines, necessary steps, engine starter- |
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| <p>tip pogona in uporabnost.</p> <ul style="list-style-type: none"> - Posebnosti zagona na tleh in med letom, ustrezno zaporedje korakov pri zagonu motorja helikopterja, vloga zaganjalnika kot generatorja. - Postopek zagona motorja in potek parametrov med zagonom, meja samovzdrževanja vrtilne frekvence. - Ukrepi ob neuspešnem zagonu, prekinitev zagona. <p>13. Krmiljenje turbinskih motorjev</p> <ul style="list-style-type: none"> - Razvrstitev krmilnih enot glede na njihove vloge, pooblastila in elektromehanski sistem. - Uvedba krmilnikov z dvema signalnimi potmi, razširitev nabora senzorjev, zagotavljanje redundance. - Nabor parametrov, ki jih spremlja in upravlja elektronska krmilna enota s polnimi pooblastili, spremljanje stanja motorja. - Zagotavljanje neodvisnosti, sistem napajanja, povezava z ostalimi krmilnimi enotami na letalu. <p>14. Pomožni sistemi in pomožna pogonska enota</p> <ul style="list-style-type: none"> - Topologija pomožne pogonske enote, njena umestitev v letalu in funkcije, ki jih opravlja. - Omejitve pri zagonu in obratovanju glede na višino leta, varnostni mehanizmi za zaustavitev. - Porabniki in viri komprimiranega zraka, razvod in upravljanje med različnimi viri. <p>15. Zmožljivosti motorjev z ozirom na parametre leta</p> <ul style="list-style-type: none"> - Definicija nazivne, največje in največje kontinuirane moči, časovni intervali uporabe. - Potek parametrov motorja med vzletom, letom in pristankom. - Vpliv višine leta, hitrosti leta, vrtilne frekvence, rabe komprimiranega zraka ter pomožnih komponent in temperature na moč, specifično porabo goriva in izstopno temperaturo iz turbine. - Pristopi za trenutno povečevanje moči/potisne sile. | <p>generator.</p> <ul style="list-style-type: none"> - Engine start-up and corresponding operational parameters, self-sustaining rotational speed. - hot start, aborted start, Measures after unsuccessful start. <p>13. Turbine engine control.</p> <ul style="list-style-type: none"> - Classification of control units according to their roles, authority and electro-mechanical systems. - Introduction of controllers with several channels, redundancy of sensors. - Monitoring and control parameters of FADEC, engine monitoring and control. - Controller independence, energy supply system, connection between controllers. <p>14. Auxiliary systems and auxiliary power unit</p> <ul style="list-style-type: none"> - Auxiliary power unit topology, role and functions within the aircraft. - Limitations during engine start-up and operation on flight level, safety mechanisms for shutdown. - Compressed air supply, distribution and management. <p>15. Turbine engine performance</p> <ul style="list-style-type: none"> - Definition and usable intervals of cruise, take-off and maximum continuous power. - Engine operational parameters during take-off, cruise and landing. - Impact of flight level, flight speed, rotational speed, bleed air usage, auxiliary loads on power, specific fuel consumption, and turbine outlet temperature. - Approaches for short term power/thrust increase. |
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Temeljna literatura in viri/Readings:

1. S. Jeppesen. Joint aviation authorities ATPL Powerplant manual, Book 4. 2007
2. F. Trenc, T. Katrašnik. Letalski motorji. Ljubljana: Fakulteta za strojništvo, 2015.
3. S. Farokhi. Aircraft propulsion. John Wiley & Sons; 2008.

Cilji in kompetence:

Cilji:

1. Razumeti teoretične osnove in procese v turbinskih motorjih
2. Spoznati komponente in procese v komponentah turbinskih motorjev
3. Spoznati interakcije in soodvisnosti procesov v turbinskih motorjih
4. Spoznati različne zasnove turbinskih motorjev in razumeti njihove značilnosti in prednosti
5. Razumeti in znati aplicirati metode za zvišanje izkoristka in povišanje potisne sile turbinskih motorjev
6. Spoznati pristope za zmanjševanje izpustov onesnažil turbinskih motorjev
7. Razumeti pristope za razvoj naprednih-okolju prijaznejših turbinskih motorjev

Kompetence:

1. Sposobnost upravljanja in vzdrževanja turbinskih motorjev (S1-PAP, S7-PAP)
2. Razumevanje fizikalnih pojavov in procesov v turbinskih motorji (P1-PAP)
3. Obvlada temeljna strokovna znanja na področju komponent in sistemov turbinskih motorjev (P3-PAP)
4. Obvlada specifična znanja na področju komponent in sistemov turbinskih motorjev, ki omogočajo aplikativna, inženirska in strokovno organizacijska dela (P8-PAP, P9-PAP)

Objectives and competences:

Objectives:

1. Understanding of theoretical basics and processes in turbine engines.
2. Knowledge turbine engine components and related processes.
3. Knowledge on interaction and co-dependence of processes in turbine engines.
4. Knowledge on different types of turbine engines and their advantages and drawbacks.
5. Understanding and knowledge on applying methods for increase in propulsive efficiency and thrust of turbine engines.
6. Knowledge on approaches for emission reduction of turbine engines.
7. Understanding approaches for development of environmentally friendly turbine engines.

Competences:

1. Ability to operate and maintain turbine engines (S1-PAP, S7-PAP)
2. Understanding of fundamental phenomena and processes in turbine engines (P1-PAP)
3. Professional knowledge on components and systems of turbine engines (P3-PAP)
4. Specific knowledge on components and systems of turbine engines that enable applied, engineering and organizational tasks (P8-PAP, P9-PAP).

Predvideni študijski rezultati:

Znanja:

Z1: Poglobljeno strokovno teoretično in praktično znanje na področju tubinskih

Intended learning outcomes:

Knowledge:

Z1: In depth professional theoretical and applied knowledge in the area of turbine

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| <p>motorjev, podprto s širšo teoretično in metodološko osnovo</p> <p>Spretnosti:</p> <ol style="list-style-type: none"> 1. S1 Sposobnost upravljanja in vzdrževanja turbinskih motorjev. 2. S1.2 Samostojna uporaba pridobljenega znanja pri analizi in diagnostiki turbinskih motorjev. 3. S1.4 Sposobnost nadaljnjega, samostojnega študija. | <p>engines, supported by comprehensive theoretical and methodological basis.</p> <p>Skills:</p> <ol style="list-style-type: none"> 1. S1.2 Mastering the operation and maintenance of turbine engines. 2. S1.2 Independent use of knowledge for analysis and diagnostics of turbine engines. <p>S1.3 Capability of further independent self-learning in the area of turbine engines.</p> |
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| Metode poučevanja in učenja: | Learning and teaching methods: |
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| <p>P1 Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov.</p> <p>P2 Obravnava snovi po urejeni in vnaprej razloženi sistematiki.</p> <p>P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri.</p> <p>P4 Laboratorijske vaje.</p> <p>P5 Uporaba študijskega gradiva v obliki (e-verzija predstavitve predavanj).</p> <p>P8 Izdelava in predstavitev aplikativnih seminarskih nalog</p> <p>P10 Uporaba anket v realnem času</p> <p>P14 Virtualni eksperimenti</p> <p>P15 Uporaba video vsebin kot priprava na predavanja in vaje</p> | <p>P1: Classroom lectures with inclusion of solving selected typical and practical examples.</p> <p>P2: Presenting of the learning content in an orderly and pre-interpreted systematics</p> <p>P3: Tutorials where theoretical knowledge of lectures is supported by computational examples.</p> <p>P4: Laboratory work.</p> <p>P5: Use of study materials in format (e-version of lecture presentation).</p> <p>P8: Design and presentation of applied seminar work</p> <p>P10: Use of real-time surveys</p> <p>P14: Virtual Experiments</p> <p>P15: Using video content to prepare for lectures and exercises</p> |

| Načini ocenjevanja: | Delež/ Weight | Assessment: |
|-----------------------------------|--------------------------|------------------------|
| - Teoretične vsebine (predavanja) | 50,00 % | - Theory (lectures) |
| - Samostojno delo na vajah: | 50,00 % | - Practical coursework |

Reference nosilca/Lecturer's references:

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|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Tomaž Katrašnik:</p> <ol style="list-style-type: none"> 1. SELJAK, Tine, ŠIROK, Brane, KATRAŠNIK, Tomaž. Advanced fuels for gas turbines : fuel system corrosion, hot path deposit formation and emissions. |
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Energy conversion and management, ISSN 0196-8904. [Print ed.], Oct. 2016, vol. 125, str. 40-50

2. SELJAK, Tine, PAVALEC, Klemen, BUFFI, Marco, VALERA-MEDINA, Augustin, CHIARAMONTI, David, **KATRAŠNIK, Tomaž**. Challenges and solutions for utilization of bioliquids in microturbines. *Journal of engineering for gas turbines and power*, ISSN 0742-4795, Oct. 2018, vol. 141, iss. 3, f. 1-9
3. SELJAK, Tine, RODMAN OPREŠNIK, Samuel, KUNAVER, Matjaž, **KATRAŠNIK, Tomaž**. Wood, liquefied in polyhydroxy alcohols as a fuel for gas turbines. *Applied energy*, ISSN 0306-2619, Nov. 2012, vol. 99, str. 40-49