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Energy Safety Management: Mitigating Loss of Control Inflight

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ENERGY SAFETY MANAGEMENT

Mitigating Loss of Control Inflight

Juan Merkt

NTAS 2017

Energy Safety Management (ESM)

- What is it?
- Why is it important?
- The training challenge
- The ESM solution
- Current efforts
- Next steps

ESM: What Is It?

Best practice for monitoring and controlling the airplane's flight path and airspeed, using energy management knowledge, rules and skills designed to mitigate hazards caused by unsafe or degrading energy states.

Merkt and Amelink (2017). Energy Safety Management: Knowledge, Rules and Skills for Safe Flight Path and Airspeed Control. Submitted for publication.

ESM: Why is it Important?

Failure to manage energy associated with vertical flight path (altitude) and airspeed

ESM: Why is it Important?

U.S. Department of Transportation
Federal Aviation Administration

FAA-S-ACS-6A

Private Pilot – Airplane
Airman Certification Standards

June 2017

- Demonstrate understanding of *energy management concepts*

Flight Standards Service
Washington, DC 20591

U.S. Department of Transportation
Federal Aviation Administration

FAA-S-ACS-7
(Change 1)

Commercial Pilot – Airplane
Airman Certification Standards

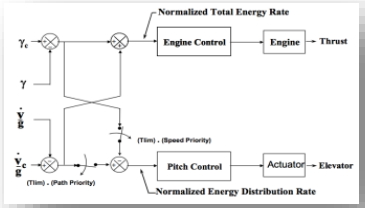
June 2017

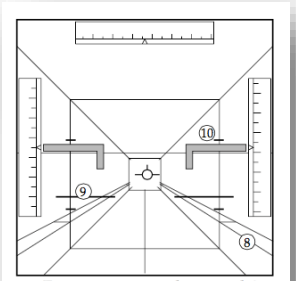
- Demonstrate understanding of *energy management concepts*
- Demonstrate ability to identify, assess, and mitigate risks resulting from *failure to manage energy*

Flight Standards Service
Washington, DC 20591

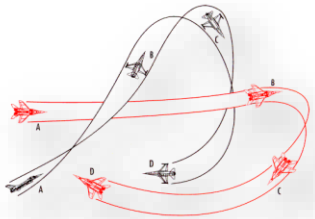
Wealth of (Inaccessible) Information for Pilots

- Fundamental Physics
  - Law of Conservation of Energy
  - Newton's Laws of Motion
- Engineering: automated flight control system
  - Total Energy Control System (TECS)
  - Tony Lambregts at Boeing (1983)
- Engineering: primary flight displays
  - Energy-augmented PFD
  - Matthijs Amelink (2005)
- Military Science: air combat tactics
  - Energy Maneuverability (EM)
  - Edward Rutowski (1954), John Boyd (1960s)
- Biology: long-range non-stop bird flight
  - Fuel Energy Height (h_{fuel})
  - Colin Pennycuick (2003)



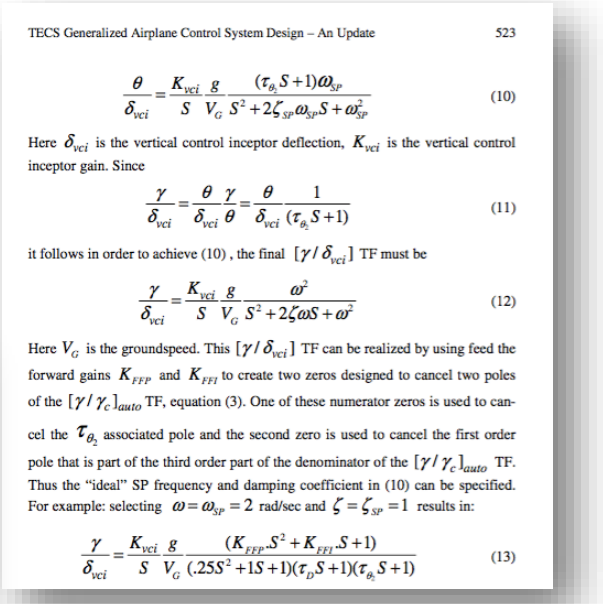


(b) Energy–augmented tunnel–in–the–sky display



Energy Management Training Challenge

- Making laws of physics and energy management applications accessible to civilian pilots
- How do we go from this?



TECS Generalized Airplane Control System Design – An Update 523

$$\frac{\theta}{\delta_{vci}} = \frac{K_{vci}}{S}\frac{g}{V_G}\frac{(\tau_{\theta_2}S+1)\omega_{SP}}{S^2+2\zeta_{SP}\omega_{SP}S+\omega_{SP}^2} \quad (10)$$

Here δ_{vci} is the vertical control inceptor deflection, K_{vci} is the vertical control inceptor gain. Since

$$\frac{\gamma}{\delta_{vci}} = \frac{\theta}{\delta_{vci}}\frac{\gamma}{\theta} = \frac{\theta}{\delta_{vci}}\frac{1}{(\tau_{\theta_2}S+1)} \quad (11)$$

it follows in order to achieve (10) , the final $[\gamma/\delta_{vci}]$ TF must be

$$\frac{\gamma}{\delta_{vci}} = \frac{K_{vci}}{S}\frac{g}{V_G}\frac{\omega^2}{S^2+2\zeta\omega S+\omega^2} \quad (12)$$

Here V_G is the groundspeed. This $[\gamma/\delta_{vci}]$ TF can be realized by using feed the forward gains K_{FFP} and K_{FFI} to create two zeros designed to cancel two poles of the $[\gamma/\gamma_c]_{auto}$ TF, equation (3). One of these numerator zeros is used to cancel the τ_{θ_2} associated pole and the second zero is used to cancel the first order pole that is part of the third order part of the denominator of the $[\gamma/\gamma_c]_{auto}$ TF. Thus the "ideal" SP frequency and damping coefficient in (10) can be specified. For example: selecting $\omega=\omega_{SP}=2$ rad/sec and $\zeta=\zeta_{SP}=1$ results in:

$$\frac{\gamma}{\delta_{vci}} = \frac{K_{vci}}{S}\frac{g}{V_G}\frac{(K_{FFP}.S^2+K_{FFI}.S+1)}{(.25S^2+1S+1)(\tau_D S+1)(\tau_{\theta_2}S+1)} \quad (13)$$

- To this:

The ESM Solution

- Analogies (Knowledge)
- Plain language (Rules)
- Pilot-oriented (Skills)

ESM Knowledge, Rules and Skills

- KNOWLEDGE: offers coherent and simple mental model of airplane as an energy system

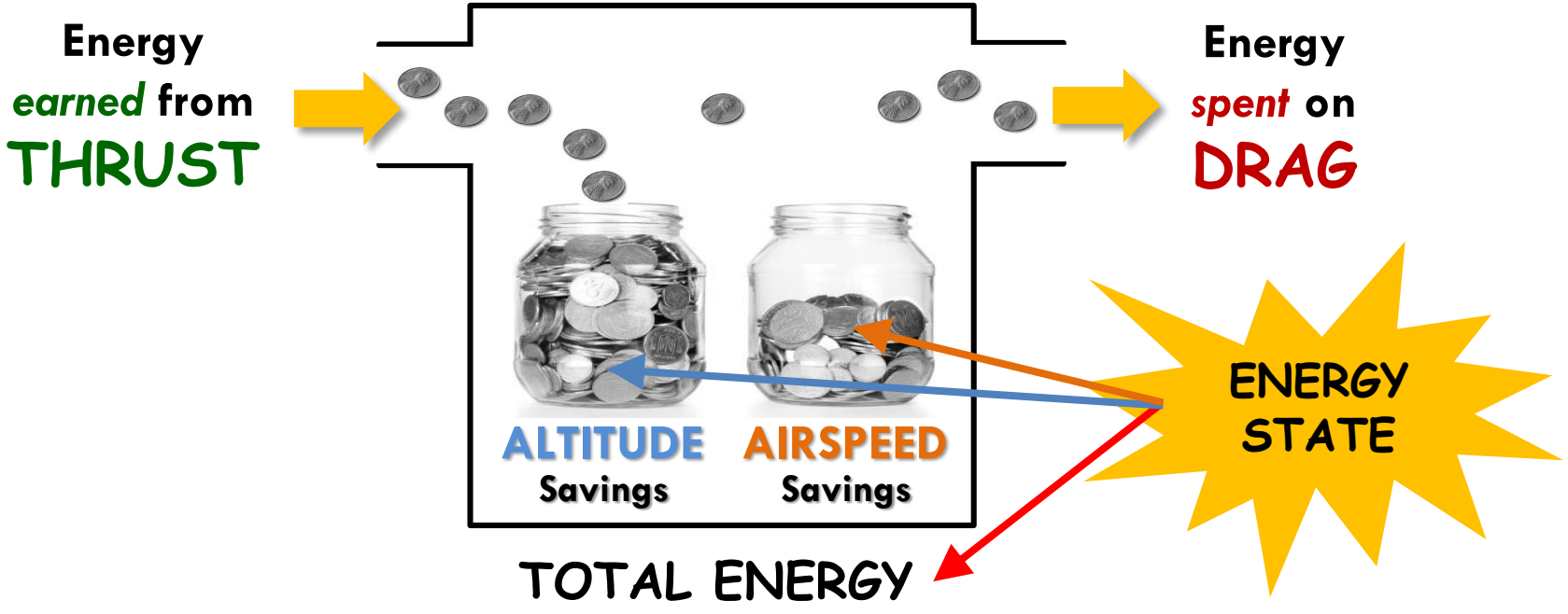
- RULES: offers a set of "energy control rules" that makes what pilots do with the controls consistent with how the airplane works

- SKILLS: adds a new set of stick-and-rudder "energy error management" skills to the general repertoire of piloting skills

THE KNOWLEDGE

DEVELOPING A MENTAL MODEL OF THE AIRPLANE AS AN ENERGY SYSTEM

The Money Analogy

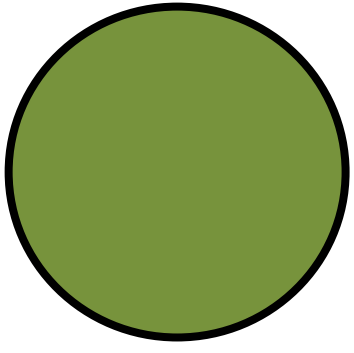


Adapted from Merkt and Amelink (2017). Energy Safety Management: Knowledge, Rules and Skills for Safe Flight Path and Airspeed Control. Submitted for publication.

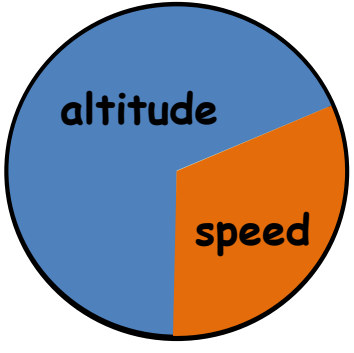
Managing the Energy State

- It means controlling:

① total energy



② energy distribution



THE RULES

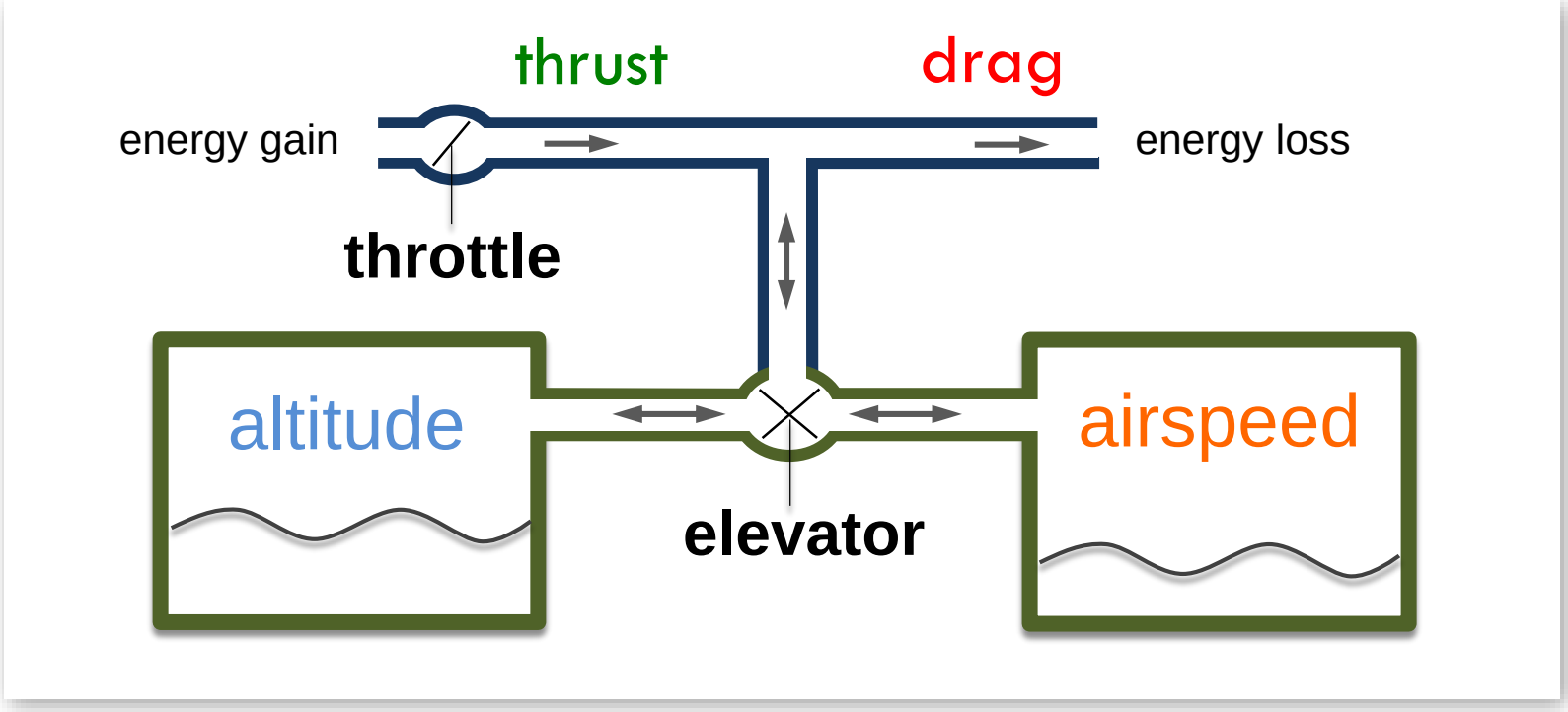
CONTROLLING THE ENERGY STATE OF THE AIRPLANE

Energy Role of the Controls

- **Throttle** is the TOTAL ENERGY Controller

- **Elevator** is the ENERGY DISTRIBUTION Controller

The Reservoir Analogy



Adapted from Amelink et al., 2005. Theoretical foundations for a total energy-based perspective flight path display. *The International Journal of Aviation Psychology, 15 (3)*, 205–231.

THE SKILLS

MANAGING ENERGY ERRORS

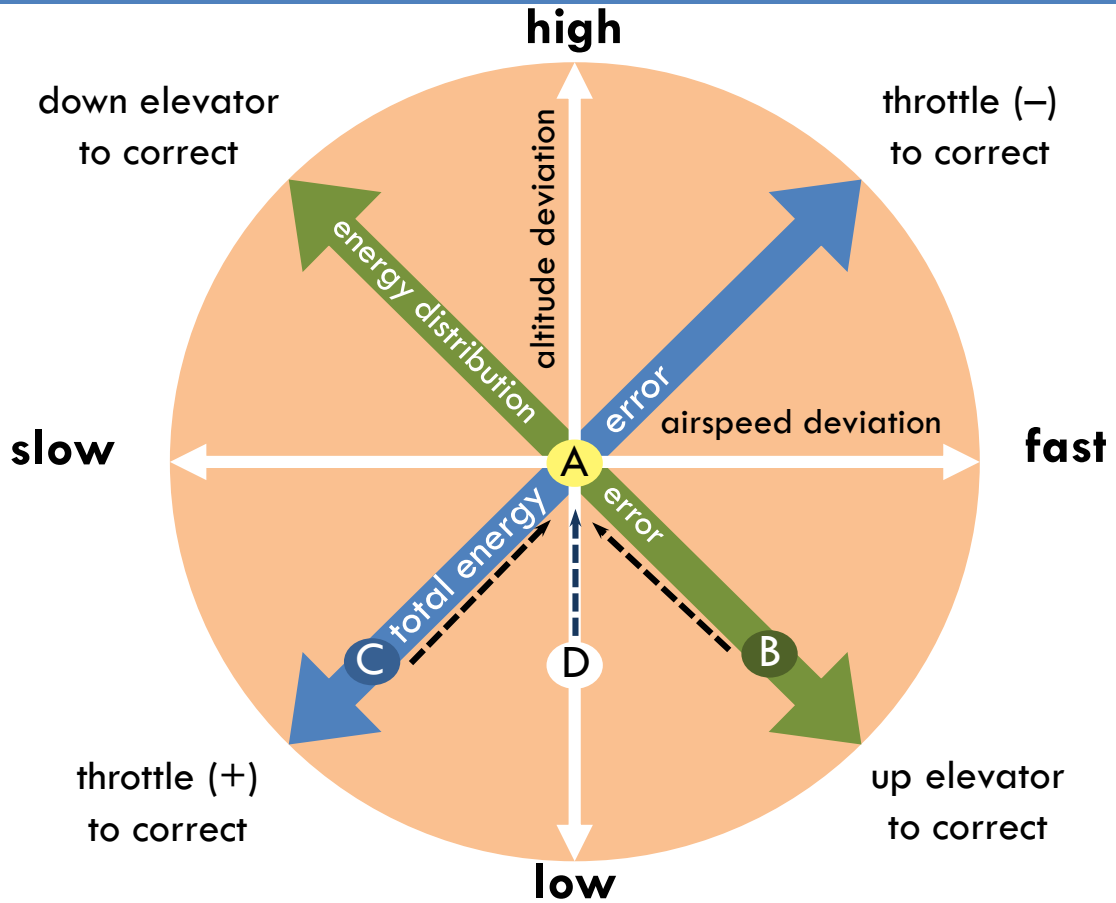
Energy Error Management

- Most inflight "energy crises" result from undetected, ignored or poorly managed path/speed deviations, hence the need for skills to recognize, correct, and prevent unstabilizing deviations

- Although intention is to correct altitude and airspeed deviations, the pilot is always acting on the airplane's energy state

- Important to translate altitude-speed deviations into energy errors

Energy Error Management Skills



Adapted from Merkt (2015). Energy management: demystifying altitude and airspeed control. *Flight Training, 27(8)*, 46-49

Expected ESM Learning Outcomes

① Have an accurate mental model of airplane as energy system

② Be fully aware of energy state of aircraft, especially during takeoff, landing, go-around, and maneuvering

③ Effectively coordinate pitch and power to control energy state during any phase of flight

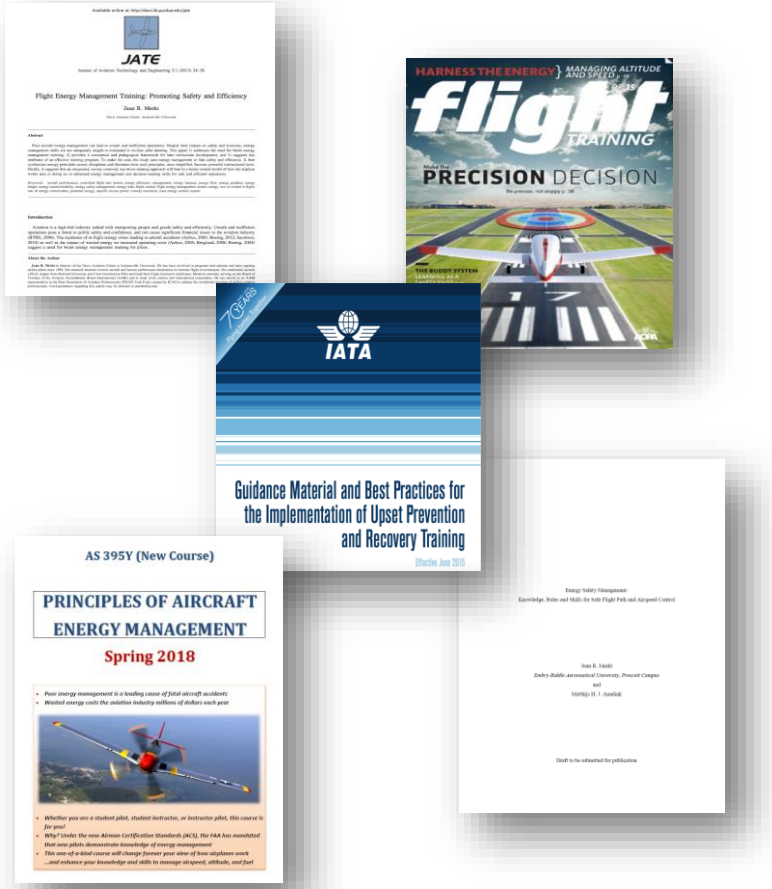
④ Confidently apply stick-and-rudder energy skills to correct path-speed deviations and maintain safe control when handling airplane near edges of energy envelope

ESM: The Bottom Line

- A fundamentally new approach to flight training
- Teaches pilots to fly an airplane as energy system
- Goal is improving aviation safety and efficiency

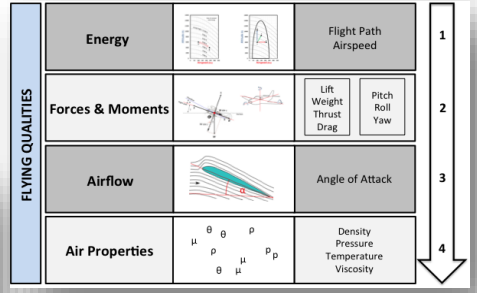
Current Efforts

- Flight Energy Management Training: Promoting Safety and Efficiency published in the Journal of Aviation Technology and Engineering (JATE 2013)
- Articles in pilot magazines and recognition in 2015 IATA Manual: "Guidance Materials and Best Practices for the Implementation of UPRT"
- Energy Safety Management: Knowledge, Rules and Skills for Safe Flight Path and Airspeed Control submitted for publication with co-author *Matthijs Amelink* (July 2017)
- New ERAU course Principles of Aircraft Energy Management in Spring 2018

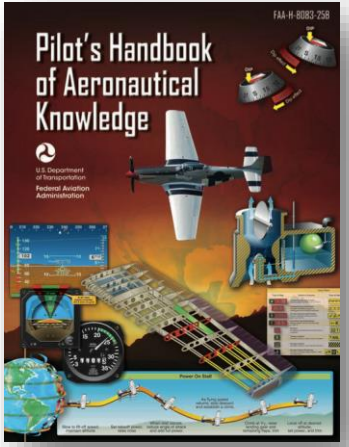


Next Steps

- Develop ESM training curriculum using a top-down approach



- Collaborate with regulators to update guidance materials



- Collaborate with academia and industry to develop ESM training tools and energy-augmented displays

QUESTIONS?

For more information:

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- http://docs.lib.purdue.edu/jate/vol3/iss1/6/
- https://www.aopa.org/news-and-media/all-news/2015/august/flight-training-magazine/energy-management