Hochschule für Angewandte Wissenschaften Hamburg
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AERO – AIRCRAFT DESIGN AND SYSTEMS GROUP

A HANDBOOK METHOD FOR THE ESTIMATION OF POWER REQUIREMENTS FOR ELECTRICAL DE-ICING SYSTEMS

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MOZART –
Health Monitoring von
Brennstoffzellensystemen
in der Luftfahrt

Deutscher Luft- und Raumfahrtkongress 2010

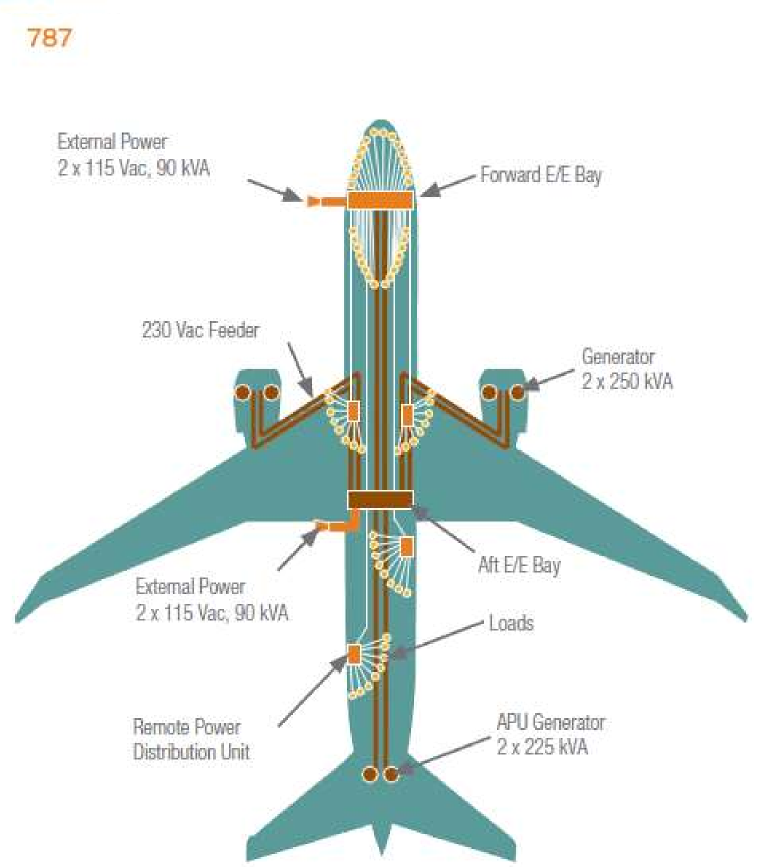
German Aerospace Congress 2010

Hamburg, Germany, 31.8.-02.09.2010 **DLRK2010-1291**

Contents

Motivation

- Vision of an "More Electric Aircraft"
- Mike Sinnett, Director, 787 Systems:
  "787 No-Bleed Systems: **Saving Fuel** and Enhancing Operational **Efficiencies**"
- Prove benefits in **trade off studies** during early phase of a project
- Required: Quick and easy to use **handbook method**



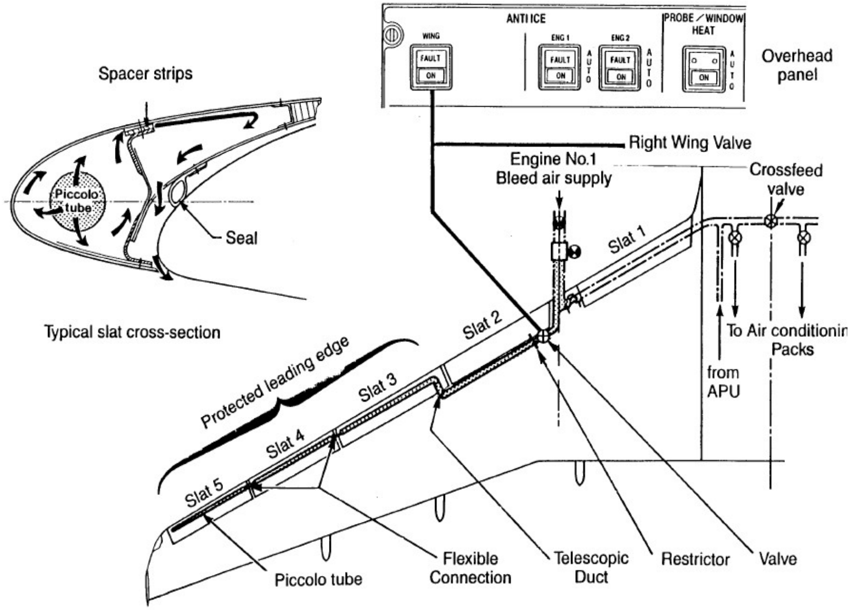
www.boeing.com/commercial/aeromagazine, aero quarterly, 04 | 07

Aim

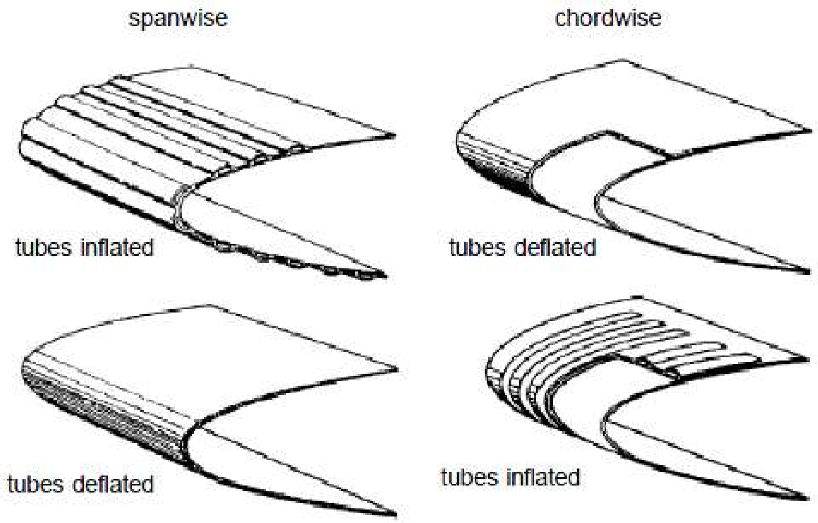
- **Estimation of power requirements for electrical de-icing systems**
- Review and improve handbook methods
- Contribution to the preliminary sizing of electrical de-icing systems
- **Simplification of trade-off studies**

Today’s Aircraft Anti-Icing and De-Icing Systems

- **Present System**
  - classically done with **bleed air** taken from the engines
  - **boot surfaces** remove ice accumulations mechanically by alternately inflating and deflating tubes



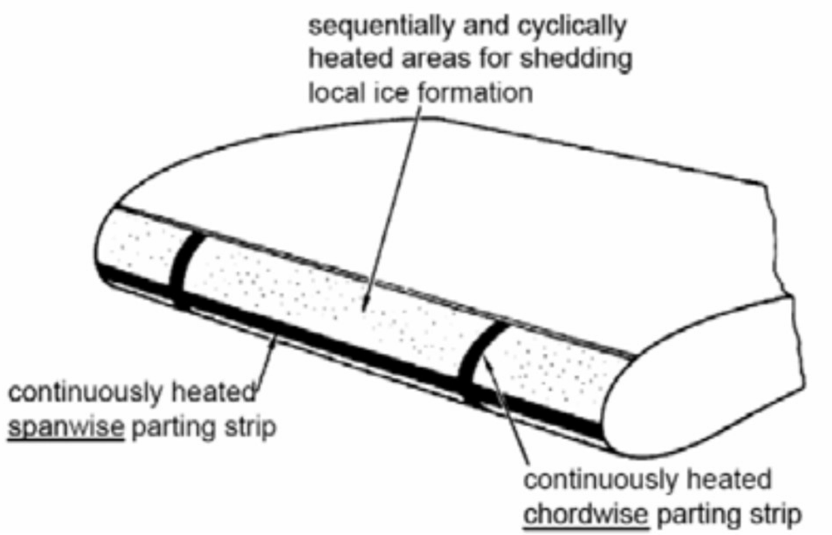
AIRBUS



FAA: Aircraft Icing Handbook, 1993

Present and Future Electrical Wing De-Icing Systems

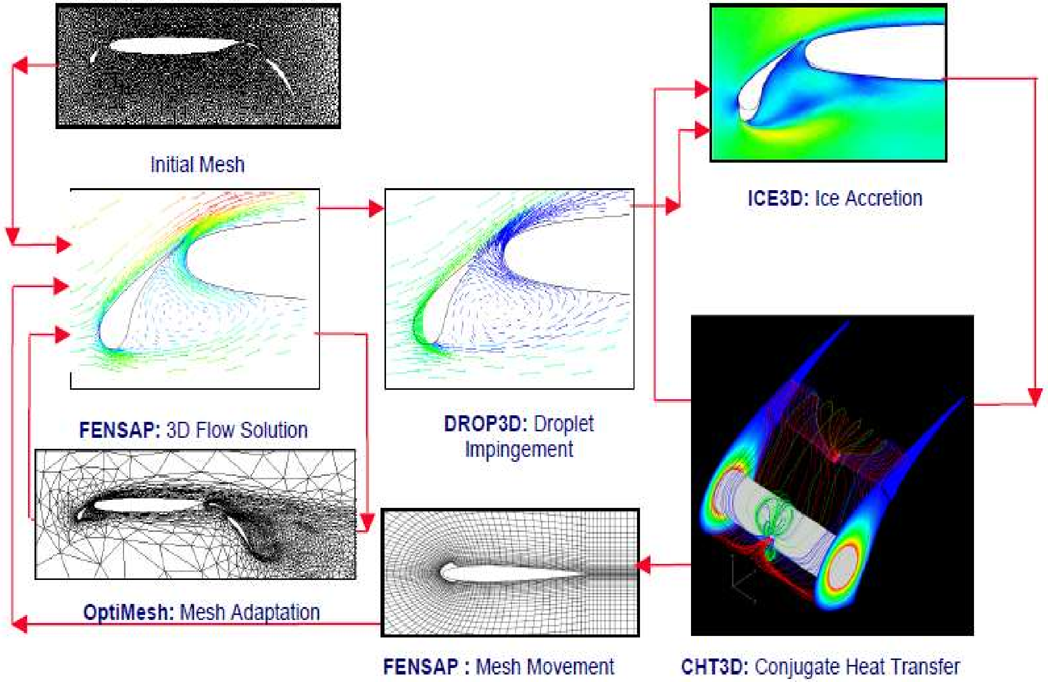
- Electrical power taken from generators on board
- (maybe too) high power demands
- Solution:
  - **Cycling heating** of main surfaces
  - Only **parting strips** permanently heated
- Energy saving:
  - Only melting of ice in contact to surface
  - Most of solid ice carried away by aerodynamic forces



FAA: Aircraft Icing Handbook, 1993

State-of-the-Art in CFD Approaches for Ice Accretion with Heat Transfer

- Icing CODES:
  - FENSAP-ICE CODE
  - CANISE CODE
  - ONERA CODE
- The methods include the whole process from flow solver to accretion and remeshing tools
- Consider the heat transfer and distribution



Wagdi G. Habashi, Pascal Tran, Guido Baruzzi Martin Aubé and Pascal Benquet, Design of Ice Protection Systems and Icing Certification Through the FENSAP-ICE System, Newmerical Technologies, Paper, 2002

State-of-the Art in Handbook Methods

- SAE: *Ice, Rain, Fog and Frost Protection*, 1990 (AIR 1168/4)
  - Mainly based on empirical equations
  - Imperial Units

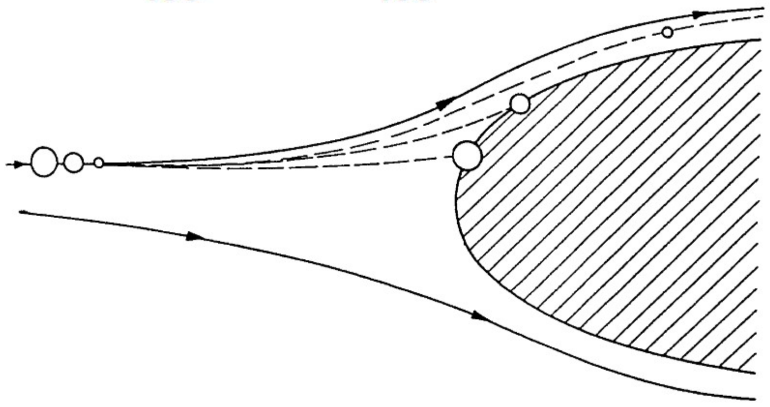
- But: Necessity for …
  - International approach with …
  - Equation from thermodynamic first principals
  - SI units

Assumptions for a New Handbook Method

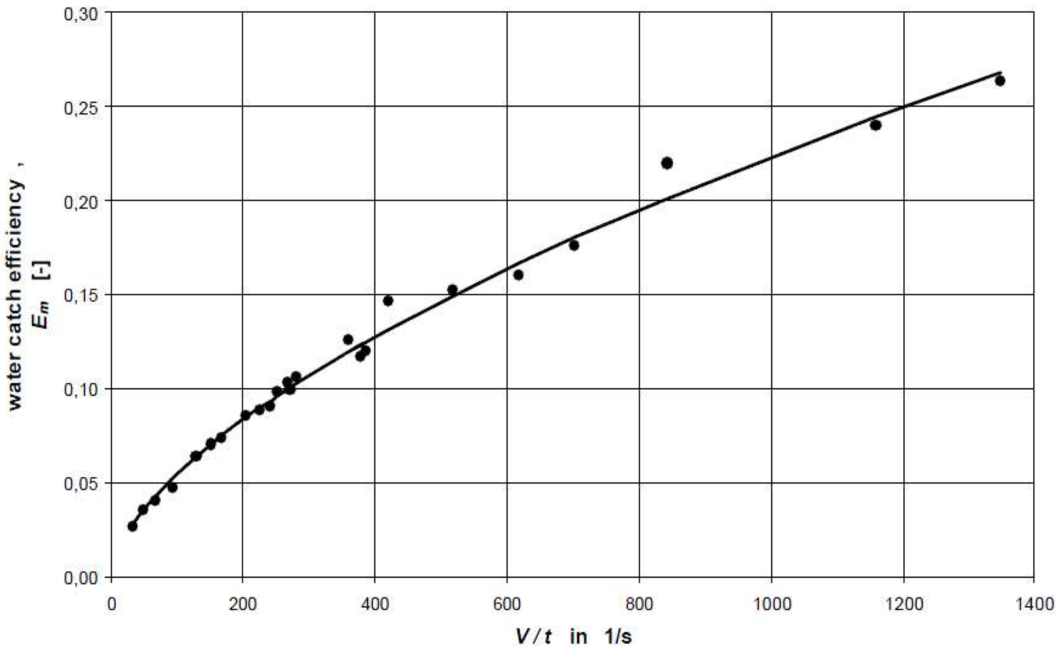
- Only two-dimensional effects are considered
- Only one point along the airfoil’s leading edge is evaluated (average values used)
- Certification rules from CS-25 required but only one design point that is considered critical is taken into account

$$\dot{m}_{ice} = v \cdot t \cdot b_{ice} \cdot \rho_{LWC} \cdot E_m$$

$$S_{ice} = t \cdot b_{ice}$$

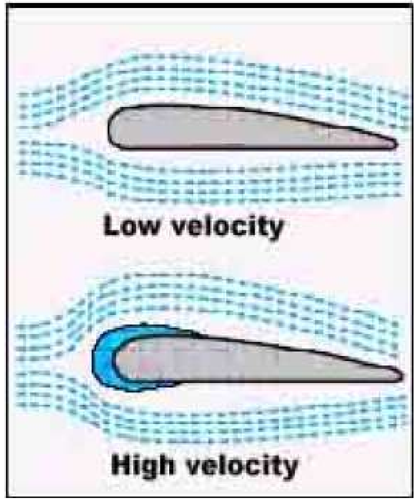


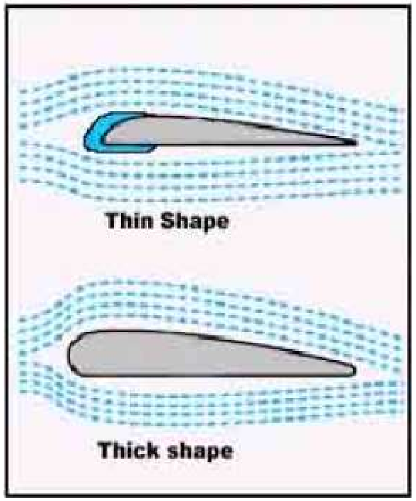
SAE: Ice, Rain, Fog, and Frost Protection, **AIR 1168/4,** 1990

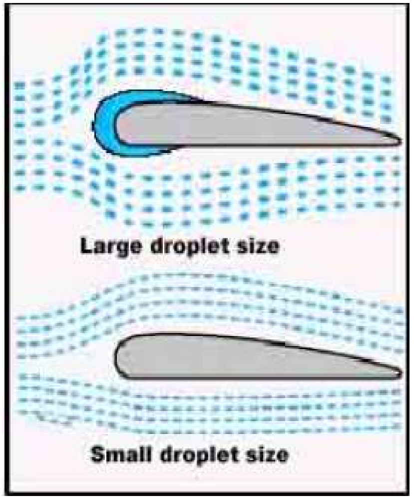


Assumptions for a New Handbook Method

- Selected design point from CS-25:
  - **Temperature** (0 °F = -17.78 °C)
  - Liquid water content (**LWC**) (guideline from CS-25 2008)
  - **Droplet diameter** (20µm)
  - **Pressure altitude** (0 ft)







Majed Sammak , Anti-Icing in Gas Turbines, Master Thesis, LUND UNIVERSITY , 2006

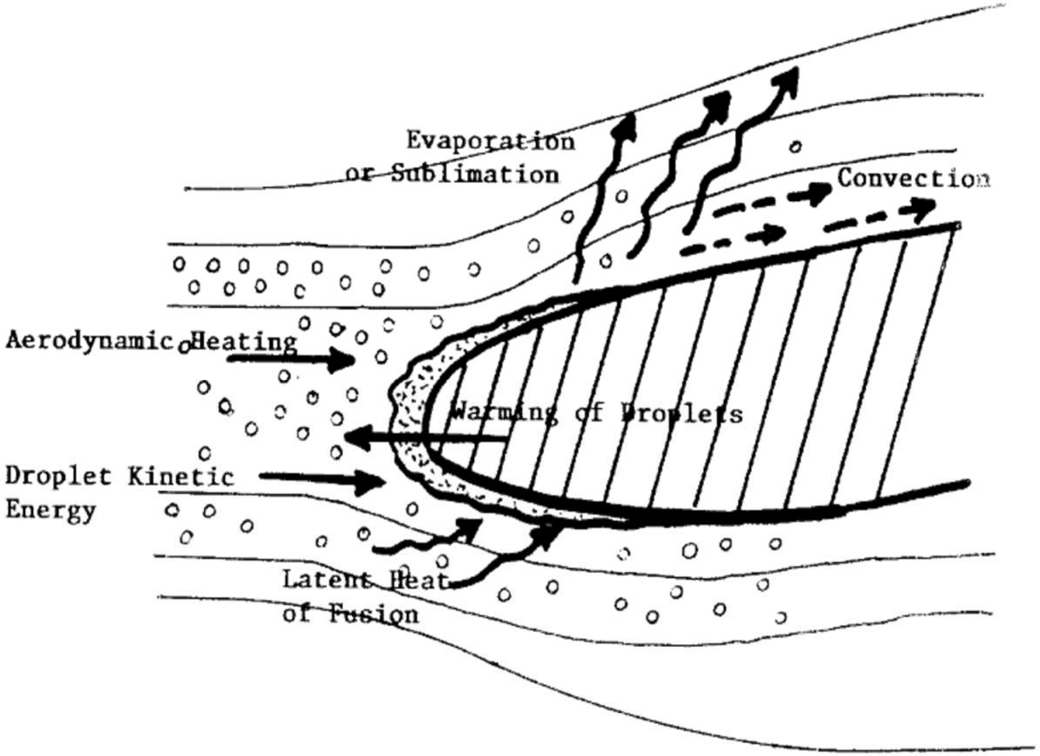
Assumptions for a New Handbook Method

- Input from CS-25.1419:
  - ***Continuous icing*** (Cumuliform Clouds):
    - » **From sea level to 22.000 ft**
    - » Typical droplet diameter**: 20 µm**
    - » **LWC** from **0.1 to 3.0 g/m³**
    - » vertical extent**: 6,500 ft**
    - » Horizontal extent**: 17.4 nm**
  - ***Intermitted icing*** (Stratiform Clouds):
    - » **4.000 to 22.000 ft**
    - » Typical droplet diameter**: 5 to 50 µm**
    - » **LWC** from **0.1 to 0.8 g/m³**
    - » Horizontal extent**: 2.6 nm**

Power Requirements for Continuously Heated Surfaces

- Power requirements calculated from a power balance:

$$\boxed{\dot{q}_{A/I} = \dot{q}_{latent} + \dot{q}_{sensible} + \dot{q}_{evap} + \dot{q}_{convec} - \dot{q}_{KE} - \dot{q}_{aero}}$$



A semi-empirical model for heat transfer and ice accretion on aircraft wings in supercooled clouds,
S.A. Sherif, N. Pasumarthi, C.S. Bartlett,
University of Florida, 1997

Power Requirements for Continuously Heated Surfaces

- The power balance consists of:
  - **Latent** heat (energy to turn ice into water)
  - **Sensible** heat (water warming up from higher surface temperature)
  - **Evaporation** (in a running-wet system: water needs energy to evaporate)
  - **Convective** cooling (energy taken away from cold airflow over surface)
  - **Kinetic** heating (impinging droplets add energy)
  - **Aerodynamic** heating (friction in boundary layer adds energy)

Results based on A320 parameters:

source	$\dot{q}_{PS}$ [kW/m²]
Example Calculation for parting strip power Requirements	11.81
AIR 1168/4 calculation scheme	14.13
AIR 1168/4 suggested value (p. 28)	18.60

Power Requirements for Cyclically Heated Surfaces

- Zones are heated up sequential in a row
- Assumptions:
  - **Ice accretions is allowed to a certain degree**
  - equilibrium temperature = ambient temperature
  - Amount of ice to be melted to destroy the bond between ice and the surface: 0.6 mm
  - Heating efficiency is assumed to be 70%.
- The calculated value does not dependent on any specific aircraft parameter.

Results based on A320 parameters:

source	$\dot{q}_{cycl}$ [$\mathrm{kW/m^2}$]
Calculated	27.25
AIR 1168/4 (p. 28)	34.10

Power Requirements for Generic Heater Layout

- cyclic de-icing uses two basic principles
  - Decrease of the continuous heated area (**parting strips**)
  - Decrease of the heat-on time (**cyclic de-icing**)

- k_{PS} gives the ratio of continuously heated parting strips against total heated area Here: **20,7%**
- k_{cycl} gives the ratio of cyclic heat on time against total cycle time. Here: **5,0%**

- Hence: $\dot{q}_{total} = \dot{q}_{PS} \cdot k_{PS} + \dot{q}_{cycl} \cdot k_{cycl}$
  - With k-factors as given above
  - $\dot{q}_{PS}$ = **17.43 kW/m^2**
  - $\dot{q}_{cycl}$: **32.69 kW/m^2**
  - The average heat load $\dot{q}_{total}$ = **5,5 kW/m^2**

Absolute Power Requirements for De-Icing

- Absolute power requirements are based on $S_{ice} = t \cdot b_{ice}$
- Required power: $P_{req} = \dot{q}_{total} \cdot S_{ice}$
- Required power for electrical de-icing of **A320**
  - 3 heated slats with b_{ice} = 15,2 m
  - Chord at middle slat (slat 4): c = 2,5 m
  - S_{ice} = 37,2 m²

$$P_{req} = 200kVA$$

- Available electrical power of A320 with one 90 kVA generator on each engine:

$$P_{elec} = 180kVA$$

Conclusion

- Calculated specific power requirements are in **good agreement with AIR 1168/4** results under the chosen assumptions

- Handbook Method allows **quick calculation of** specific de-icing **power requirements**
  1. use of given specific power requirements $\dot{q}_{total}$ (given design point, A320, k-factors)
  2. based on specific power requirements $\dot{q}_{total}$ calculated from
     a) individual design point (CS-25) and
     b) individual aircraft parameters
     c) Individual k-factors describing the heater layout

- Handbook Method with k-factors allows a **description of heater layouts**
  - with de-icing sequence (ratio of on time against cyclic heating period)
  - with specific parting strip area (ratio of parting strip area against total heating area)

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