Arnold Magnetic Technologies

Where Air Meets Ground: High Performance Materials Converge on the Horizon

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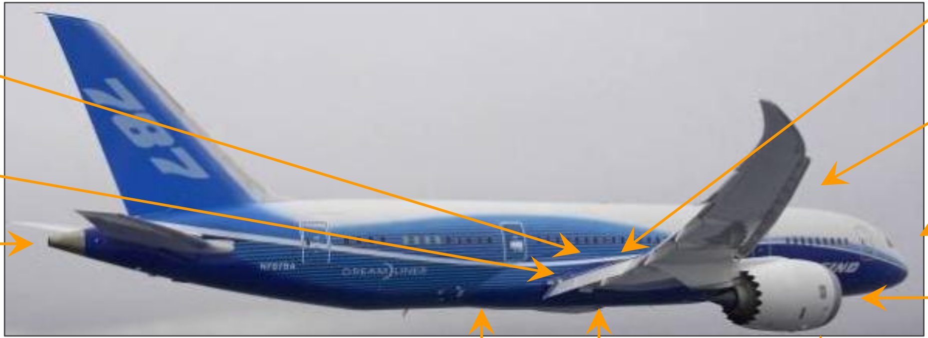
Motor Applications — *Aerospace*



- Main electrical power generator
- Aileron actuator
- APU
- HVAC system pump
- RAT (Ram Air Turbine)
- Fuel Pump
- Cabin air pressurization & recirculation
- Flap actuators
- Fly by wire joystick controls
- Engine starter/ generator

Many electrical motor/generator technologies already in place on airframes

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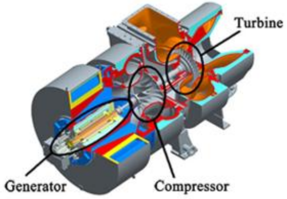
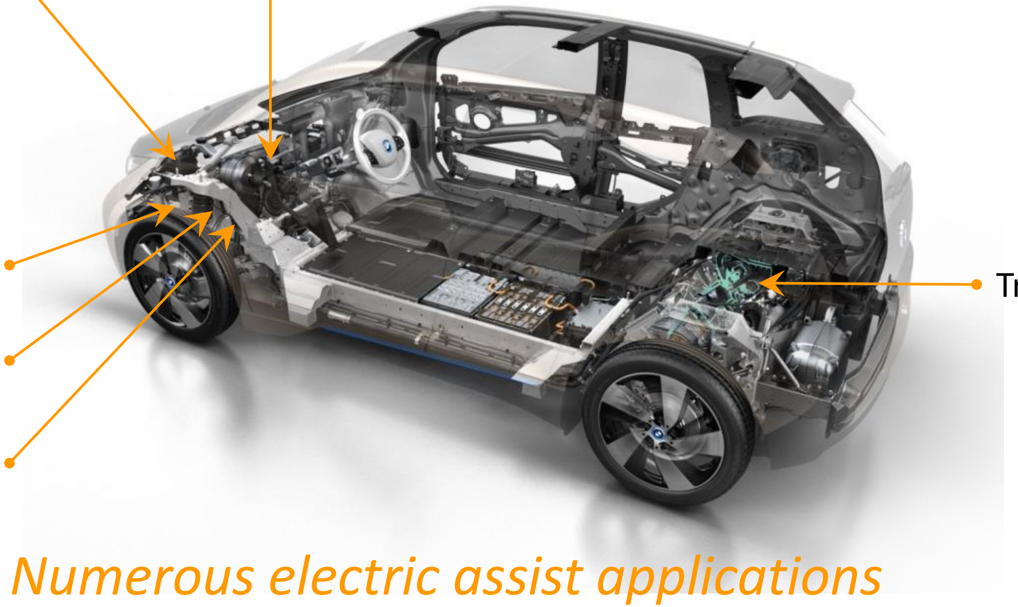
Electric Assistance Applications

eTurbo / eBoosting / HERS



Start / Stop Technology



Electric Power Steering

Electric Air-Conditioning

Electric Water Pump

Traction Drive / KERS

Numerous electric assist applications to increase vehicle efficiency

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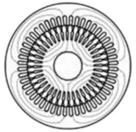
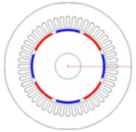
What Motor Topology to Choose?

Induction Machine



Permanent Magnet



Switched Reluctance

***Aerospace** has main focus on motor efficiency*

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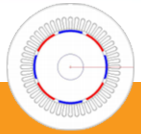
Motor Technologies — Advantages/Disadvantages


Induction Machine		Surface PM		Switched Reluctance	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
High speeds	Rotor losses (cooling)	***Energy efficiency***	Permanent magnet temp. effects	High speeds	Acoustic noise
Simple construction	Less constant power speed range	Highest torque/inertia ratio	Magnet retention	Simple rotor construction	Complex control
High torque/inertia ratio	Low power density	Highest torque density	Iron Losses	Low rotor losses at low speeds	Rotor position sensor required
High torque density	Lower efficiency over op range	Good torque control	Magnet costs	Low cost	Small air gap
Low cost		Very low rotor losses	Excitation during a winding fault	No permanent excitation	Special drive topology
No permanent excitation		Common drive topology			Motor/drive control match required
Common drive topology		Simple construction			High windage

Smaller. Faster. Hotter

Design Challenges for the Emerging Systems

- Thermal Management
- Power Density
- Higher Speeds (100K+ RPM)
- Weight Reduction
- Secure Supply Chain
- Cost

Motor Technologies have overcome these challenges in Aerospace

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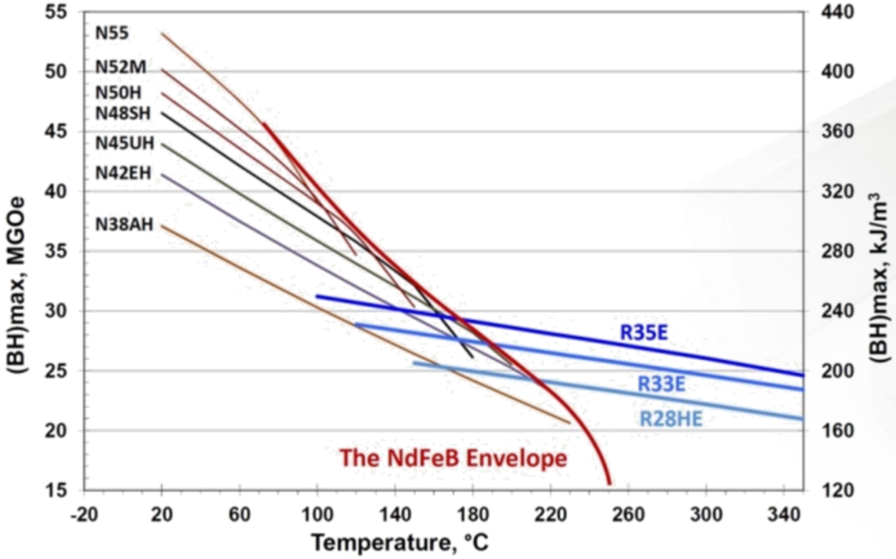
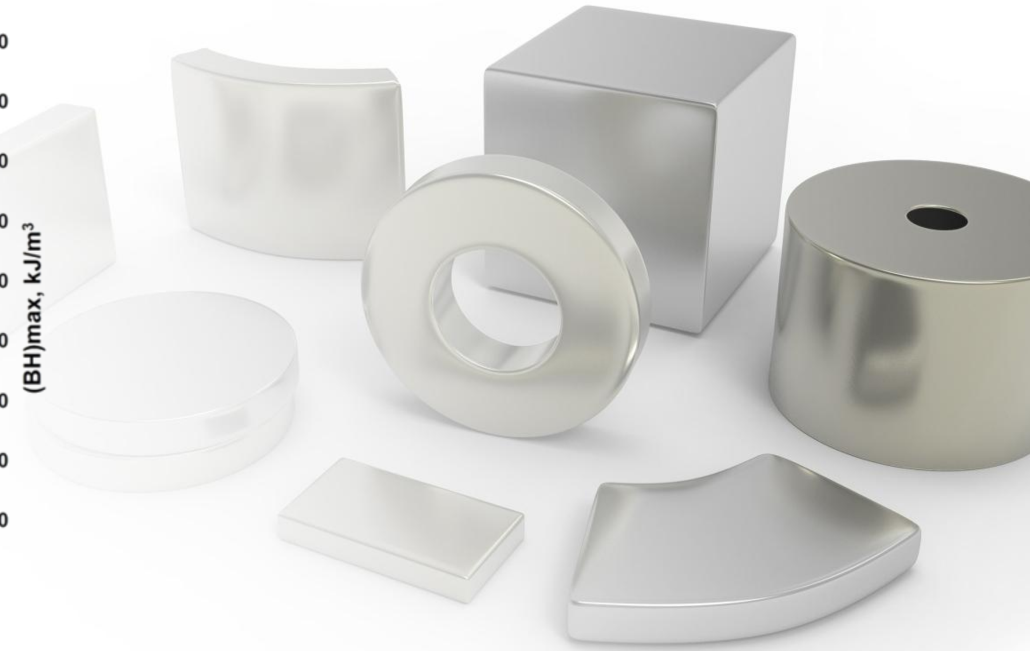
SmCo Untapped Potential





*Advancements in **SmCo magnets***
improve power density at temperature

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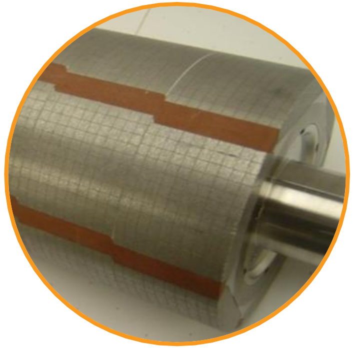
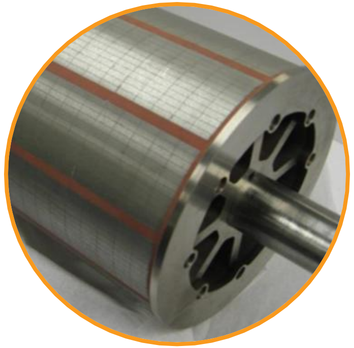
Laminated Magnet Process

- Further reduction of eddy currents (heat) for increased efficiency (Joule Loss Reduction)
- Thin insulating gap (<20 um)
  - Maximum energy density for applications





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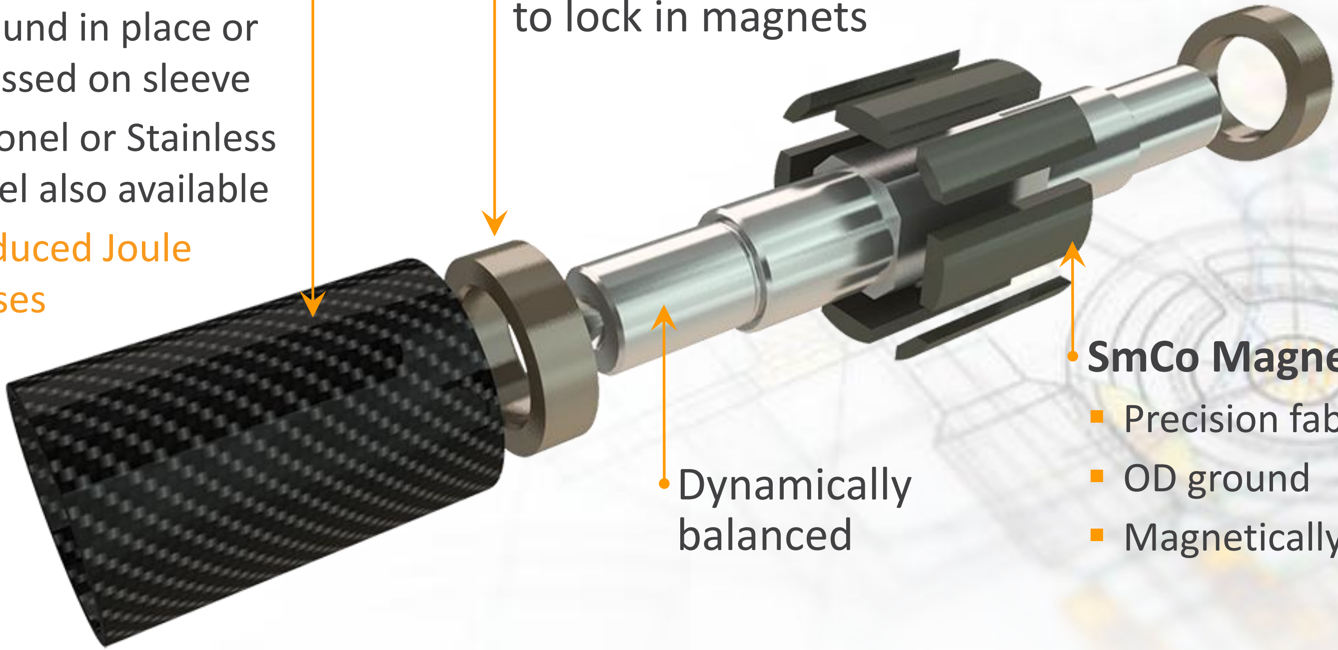
Magnet Retention at High Speeds

Composite Sleeving

- Wound in place or pressed on sleeve
- Inconel or Stainless Steel also available
- Reduced Joule losses

Precision fit end ring to lock in magnets



Dynamically balanced

SmCo Magnets

- Precision fabricated
- OD ground
- Magnetically stabilized

Speeds in excess of 150K RPM
225°C + Operating Temperatures

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Precision Thin Metals

- **Silicon Steels for High Frequency Applications**
  - Arnon – Non Oriented (0.18 mm & 0.13 mm)
  - Grain Oriented (0.03 mm - 0.15 mm)
- **Popular Materials Available**
  - Titanium & Its Alloys
  - Arnokrome (FeCrCo)
  - Nickel & Its Alloys
  - Nickel Irons & Soft Magnetics
- **Exceptionally thin strip and coil**

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Materials to Reduce Iron Losses

- Ultra thin (0.005" - 0.007") non-oriented 3% silicon steel
  - Reduces eddy current losses and heat rise in the stator
  - C5 insulation coating

Smaller ➤ Higher Flux Density

Faster ➤ Higher Frequencies

***Thinner laminations** to reduce eddy currents*

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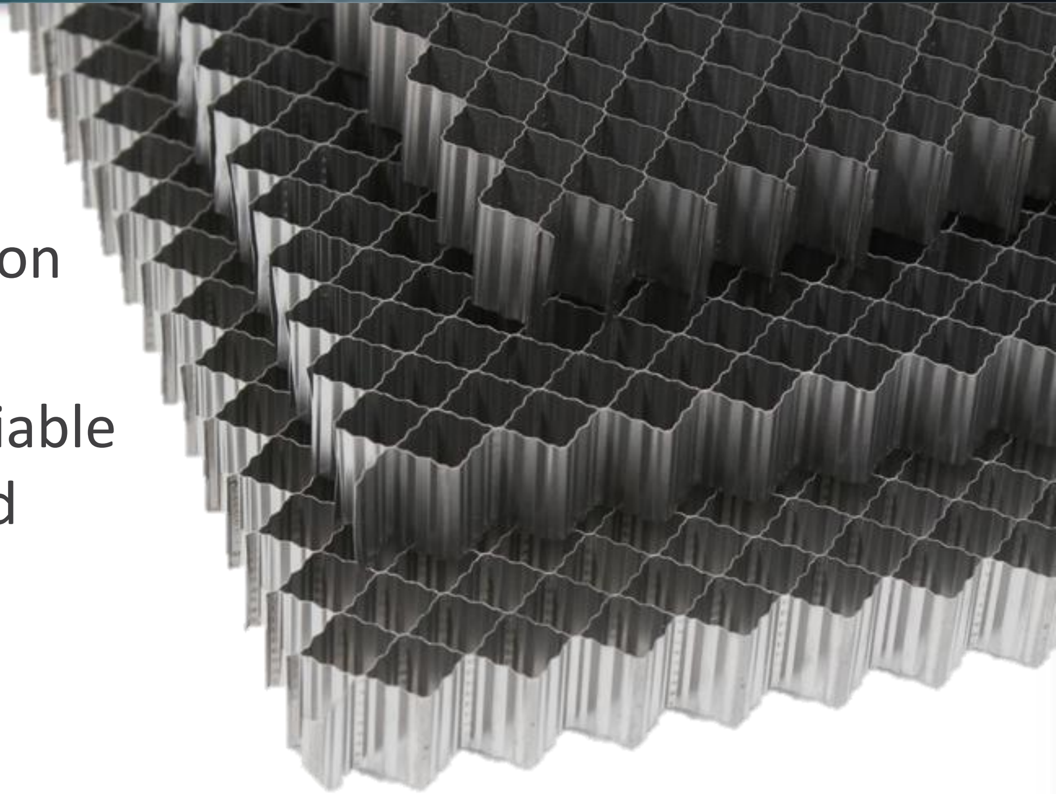
Titanium for Lightweighting

- Used for aerospace surfaces and structures
- High overall strength, corrosion resistance, and ductile
- Lightweight, durable, and reliable under harsh temperature and chemical conditions



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Summary

PM machines dominate high performance aerospace applications due to a higher motor efficiency. This technology will continue to push into the automotive landscape as motor efficiency becomes more critical.