NYCT OPERATING EXPERIENCE WITH HYBRID TRANSIT BUSES

SAE Metro Section Meeting
College of Aeronautics
November 21, 2003

New York City Transit
Department of Buses

Outline
- Overview of NYCT Bus Operations
- Hybrid Electric Bus Technology
- NYCT Hybrid Bus Projects
- Lessons Learned with Hybrids
- Future Plans

NYCT Bus Operations
- Number of Depots: 18
- Employees: 14,388
- Bus Routes / Bus Stops: 218 / 12,355
- Ridership: 2.4 million weekday
- Revenue Miles: 119 million annually
- Diesel Fuel Used: 47 million US Gal. in 2002

NYCT Bus Fleet

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>40' 2-stroke Diesel Transit</td>
<td>392</td>
<td>0</td>
</tr>
<tr>
<td>40' 4-stroke Diesel Transit</td>
<td>2,655</td>
<td>2,404</td>
</tr>
<tr>
<td>45' 4-stroke Diesel Coach</td>
<td>570</td>
<td>570</td>
</tr>
<tr>
<td>60' 4-stroke Diesel Articulated</td>
<td>566</td>
<td>695</td>
</tr>
<tr>
<td>40' CNG Transit</td>
<td>289</td>
<td>596</td>
</tr>
<tr>
<td>40' Hybrid Transit</td>
<td>10</td>
<td>335</td>
</tr>
<tr>
<td>Total</td>
<td>4,482</td>
<td>4,600</td>
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The Clean Fuel Solution - Hybrid Electric

- Hybrid Electric buses combine a diesel engine and electric drive components
- Improved performance
  - Significant emissions reduction
  - Increased fuel economy
  - Smooth and quiet operation
- Avoids the infrastructure costs of CNG - no special fuel handling is required

BAE Hybrid System

NYCT Hybrid Bus Programs

- Successful prototype in 1996 (Orion/GE)
- Pilot fleet of hybrid buses began operating in revenue service in 1998
  - 10 Orion/BAE buses
- 325 additional Orion/BAE hybrid buses ordered for delivery
  - 125 buses starting in December 2003
  - 200 buses starting in 2004

Revenue Service Experience

- Hybrid buses in service since Sept. 1998
- Meet standard performance specs and NYCT emissions - 0.06 g/mi PM and 15 g/mi NOx
- 620,000 revenue miles accumulated to date
- Drivers and customers like the buses
- Brake life approximately doubled
- Very positive - for a brand new technology, have exceeded expectations
Reviewed maintenance data for 1 year

- Compared 10 pilot hybrid buses to standard diesel buses - same duty cycle - 6.4 avg. mph
- Fuel economy was 10% higher overall - as much as 22% higher in winter
- Hybrid buses had lower reliability and higher maintenance costs consistent with their being a small pre-commercial fleet
**Hybrid Bus Reliability (MDBF*)**

- Hybrid MDBF

**Hybrid Bus Availability**

- % of Hybrid Fleet Availability

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**Lessons Learned - Operational**

- Bus operators and passengers like hybrids
  - Quiet, smooth operation
  - excellent acceleration/smooth braking
  - “feels” like a standard bus
  - little or no operator training required
- Able to be used on all NYCT routes
- Bus does not roll back on hills
- Performance can be customized

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**Lead-Acid Technology & Life Issues**

- **Negative Plate Sulfation**
  - Reversible performance and life limiter
  - Reduced or eliminated w/ proper conditioning – current 6-month conditioning cycle has proved effective
  - Likely factor in many battery failures in both EV and HEV
  - On-going research to reduce or eliminate the need for off-line conditioning (ie. conditioning “on the fly”)
- **Positive Battery Plate Grid-Corrosion**
  - Result of normal charging process - non-reversible & the ultimate life limiter in lead-acid batteries
  - True End-of-Life duration & behavior not yet established
  - Specific duty cycle and ambient temperatures will have large effect on expected life
Orion VI Lead Acid Battery Life

- All 10 battery packs over 24 months & some nearing 30 months – no indication of end of life yet
  - Only 12 infant failures (2%) – all traced to manufacturing defects addressed by manufacturer
  - Tear down tests show virtually no grid corrosion
  - Definite evidence of sulfation – but 6 month conditioning is effective at reversing it
- Current Life Expectation: ?????
- Changes to HybridDrive in Orion VII should extend battery life even further

Lead-acid Battery Sampling

**Grid Corrosion**
- Healthy grid wires – little or no corrosion
- Badly corroded grid

**Negative Plate Sulfation**
- Speckled areas near grid areas indicate sulfation

Battery Type Life/Cost Comparison

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Lead-Acid</th>
<th>NiMH</th>
<th>Lithium-Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Life (Expected)</td>
<td>2.5 – 4 yrs</td>
<td>5 – 7 yrs</td>
<td>5 – 10 yrs</td>
</tr>
<tr>
<td>Cost ($ / kW-hr)</td>
<td>$100-$150</td>
<td>$300-$500</td>
<td>&gt;&gt; $1000</td>
</tr>
<tr>
<td>Life-Cycle Cost ($/kW-hr/yr)</td>
<td>$25-$60</td>
<td>$42.86-$100</td>
<td>&gt;&gt; $100 – &gt;&gt; $200</td>
</tr>
</tbody>
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Lead-Acid Technology is still the cost winner ... for now

Orion VII Hybrid Pilot Bus

- 1st of 125 bus order – put in service July 2002
- In service for 100 days
  - Used on one of toughest routes (Avg 5.6 MPH)
  - Averaged 115 miles / 21 hours per day
  - MDBF 1,854 miles (similar to diesel)
  - Availability 85%
- NO propulsion system problems
- Fuel economy 8% better than Orion VI hybrid and 28% better than diesel buses
Orion VII Hybrid Bus

Orion VII Hybrid Fuel Economy vs Temp

Recent Hybrid Emission Results

Design Improvements - Traction Motor
- Planetary gearcase replaces offset design
- Increased coil to chassis clearance
- Redesigned high speed bearing system
- Improved coil and insulation to improve stator reliability and produceability
- Safety/EMI enclosure added to the three phase connections
- Better field maintainability
Design Improvements - Generator

- Active Control of Generator
  - Enables varying engine speed for better exhaust temperature control
  - Optimizes NOx and Fuel Economy
  - Improves Engine Transient Response by matching dynamic load to engine
- Integral Junction Box Added for High Voltage Connections

Other Design Improvements

- Catalytic exhaust filter redesigned - exhaust temperature and backpressure are monitored to optimize emissions and reliability
- Integrated Diagnostic System (IDS) improved to flag problems sooner and troubleshoot problems more easily
- Hawker XT batteries - more plate material for longer life
- Improved regen control for smoother braking

NYCT Hybrid Bus Plans 2002 - 2004

- Begin delivery of 125 Orion VII BAE hybrid buses in December 2003
- Begin delivery of 200 additional Orion VII hybrid buses in Late 2004
- Characterize end-of-life behavior with lead-acid batteries (Orion VI)
- Continue search for next generation energy storage devices
- Integrate Hybrid buses into depot operations

Additional Information

- Speaker Contact:
  Dana Lowell, Asst. Chief Maintenance Officer
  MTA New York City Transit
  (718) 927-8620; dalowell@nyct.com
- Hybrid/CNG/Diesel Emissions Report
  www.navc.org/emissionsreport.html
- NREL Reports:
  www.afdc.doe.gov/resources.html
  reports 6369 and 6383