

**MTA New York City Transit**  
Department of Buses

**NYCT OPERATING EXPERIENCE WITH HYBRID TRANSIT BUSES**

SAE Metro Section Meeting  
College of Aeronautics  
November 21, 2003

**Outline**

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

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**NYCT Bus Operations**

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- 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

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**NYCT Bus Fleet**

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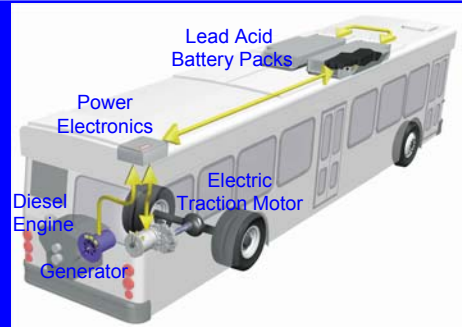
	<u>2003</u>	<u>2005</u>
40' 2-stroke Diesel Transit	392	0
40' 4-stroke Diesel Transit	2,655	2,404
45' 4-stroke Diesel Coach	570	570
60' 4-stroke Diesel Articulated	566	695
40' CNG Transit	289	596
40' Hybrid Transit	10	335
<b>Total</b>	<b>4,482</b>	<b>4,600</b>

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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

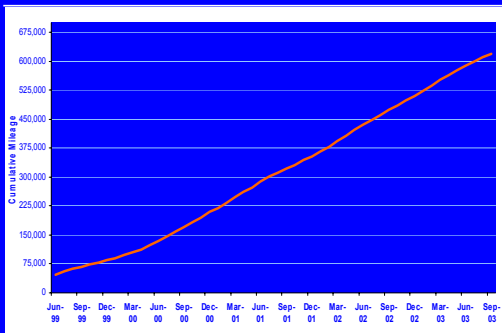
## Orion VI/BAE Hybrid Bus



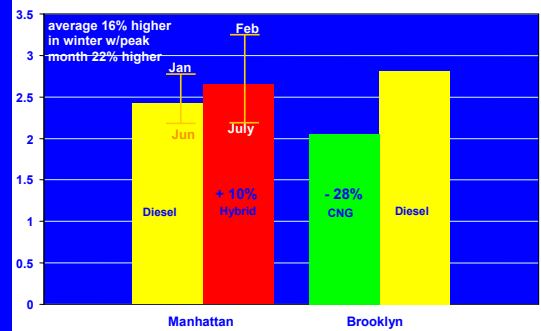
## NREL Final Data Report

- 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

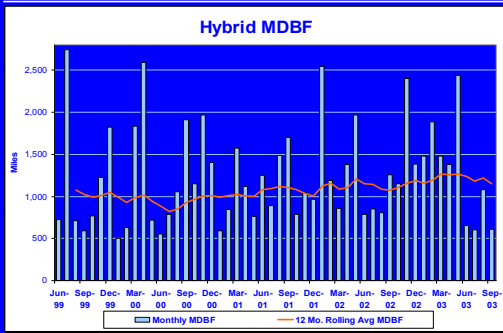
## Hybrid Bus Revenue Miles



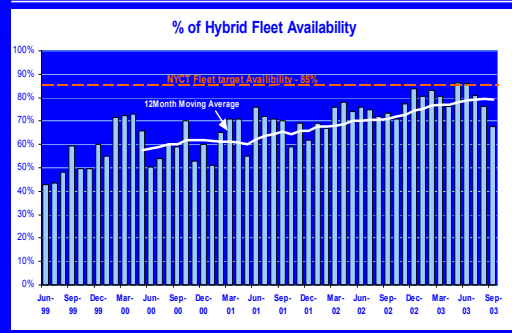
## Hybrid Bus Fuel Economy (MPG)



## Hybrid Bus Reliability (MDBF\*)



## Hybrid Bus Availability



## 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

## Lead-Acid Technology & Life Issues

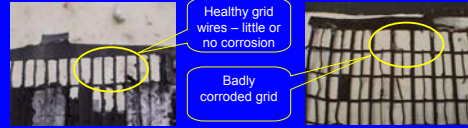
- Negative Plate Sulfation
  - ➔ Reversible performance and life limiter
  - ➔ Reduced or eliminated w/ proper conditioning – current 6 month conditioning cycle has proved effective
  - ➔ Likely factor in many battery failures in both EV and HEV
  - ➔ On-going research to reduce or eliminate the need 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



### Negative Plate Sulfation

Speckled areas near grid wires indicate sulfation



## Battery Type Life/Cost Comparison

Chemistry	Lead-Acid	NIMH	Lithium-Ion
Service Life (Expected)	2.5 – 4 yrs	5 – 7 yrs	5 – 10 yrs
Cost (\$ / kW-hr)	\$100-\$150	\$300-\$500	>> \$1000
Life-Cycle Cost (\$/kW-hr/Yr)	\$25-\$60	\$42.86-\$100	>> \$100 – >> \$200

Lead-Acid Technology is still the cost winner .... for now

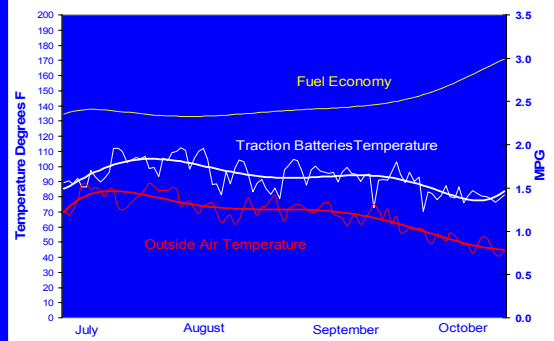
## Orion VII Hybrid Pilot Bus

- 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

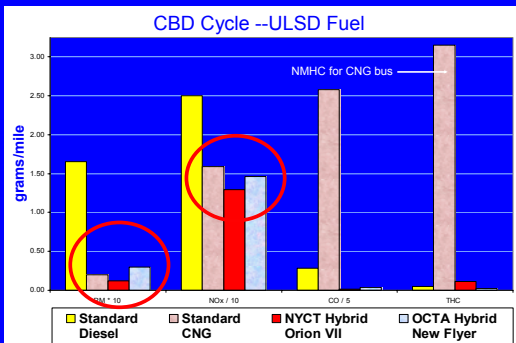
## Orion VII Hybrid Bus



## 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

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- 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
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## Other Design Improvements

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- 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
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## NYCT Hybrid Bus Plans 2002 - 2004

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- 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**
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## Additional Information

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