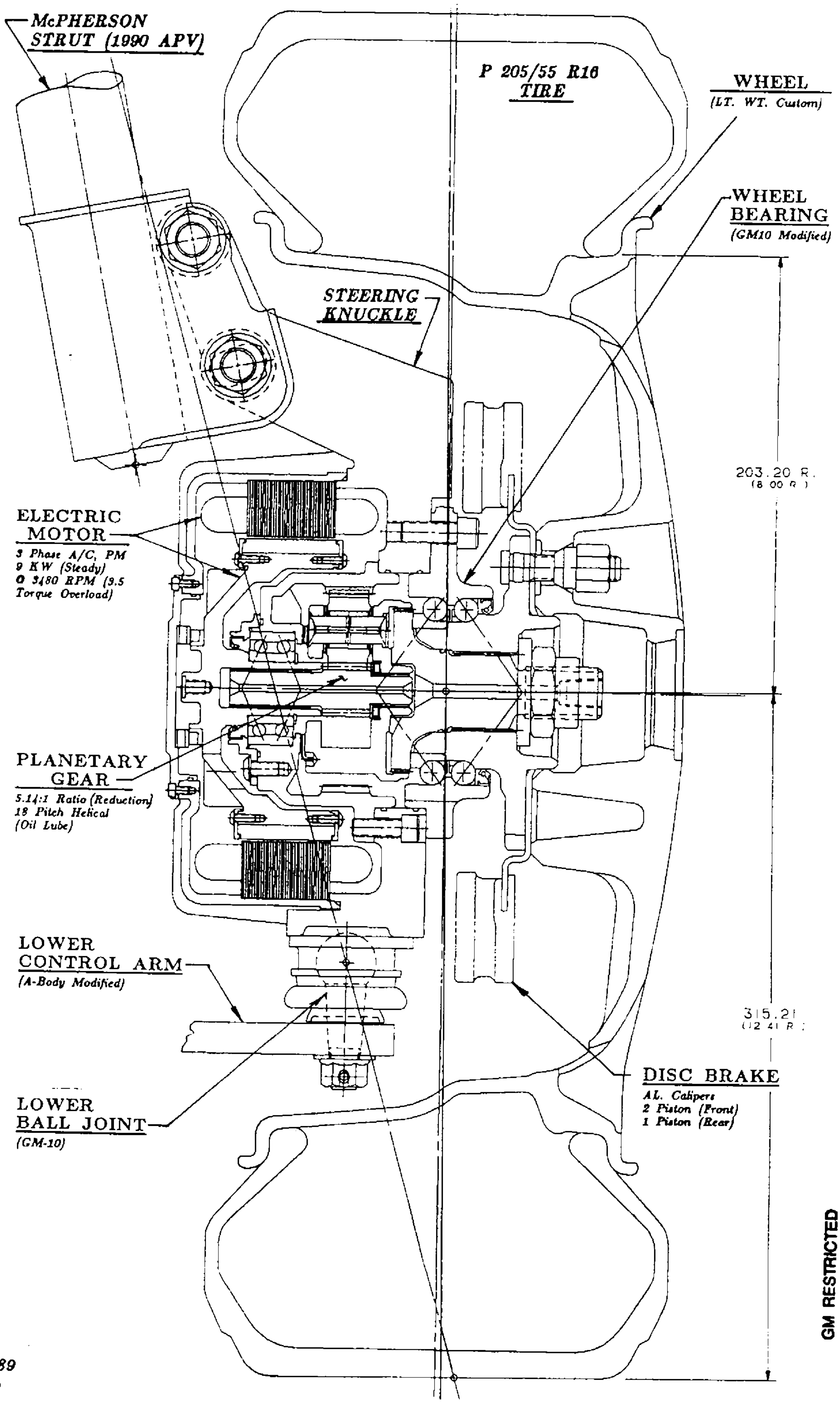
WHEEL DRIVE ASS'Y
(FREEDOM VEHICLE)



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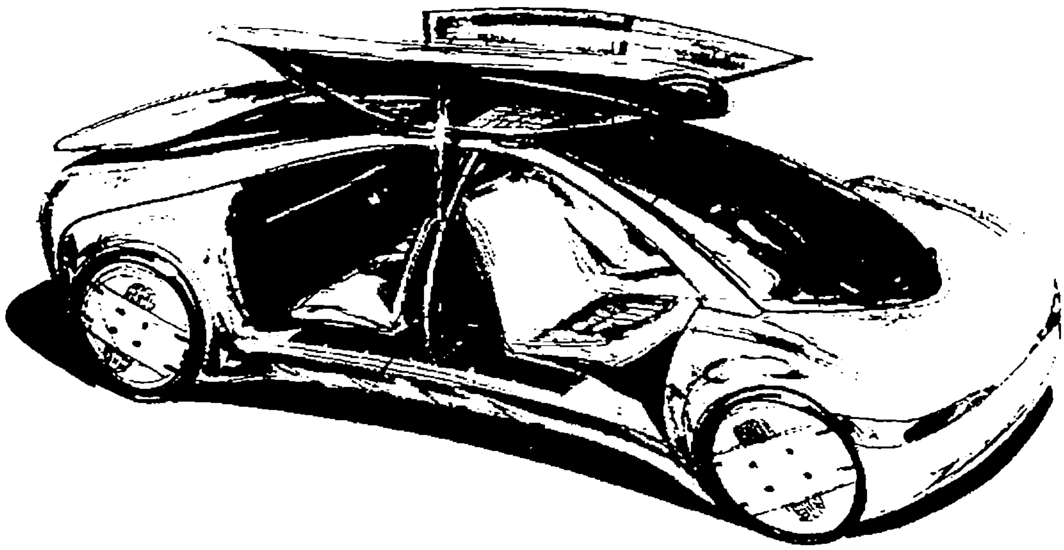
FREEDOM PROJECT

A GMR ELECTRIC/HYBRID VEHICLE CONCEPT



A TRILBY VEHICLE SYSTEMS PROGRAM
IN COOPERATION WITH
DESIGN STAFF, AES, AND DELCO REMY

G. Skellenger
Project Manager

ELECTRIC VEHICLES

- **LONG HISTORY**
- **RECENT RENEWED INTEREST**

  Air Quality in Urban Centers

  Electric Utility Load-Leveling

- **REDUCED OPERATING RANGE**

  Energy Storage Capability

Battery Type	Specific Energy, Wh/kg
Adv. Lead Acid	*35*
Nickel Zinc	*50*
Nickel Cadmium	*30*
Sodium Sulphur	*100*

For reference, gasoline = 12000 Wh/kg

HYBRID VEHICLES

- TWO (OR MORE) ENERGY STORAGE DEVICES

  (One is Petroleum-Based)

- TWO (OR MORE) POWER SOURCES

  (One is Internal Combustion Engine)

- ADVANTAGES

  Essentially Unlimited Range

  Potential for Improved Economy & Emissions

    Optimized Engine Operation

    Regenerative Braking

- DISADVANTAGES

  Cost

  Complexity

MULTIPLE POWER SOURCES

- **INSTANTANEOUS POWER *PRODUCTION* IS DECOUPLED FROM INSTANTANEOUS *REQUIREMENTS***

- **OPERATION OF THE *ENGINE* CAN BE OPTIMIZED FOR --**

  Maximum Thermal Efficiency, or

  Minimum Emissions, or

  Appropriate Compromises

MULTIPLE POWER SOURCES, continued

- ONLY THE *TOTAL* ENERGY PRODUCED,

$$\int_0^T P_{engine}\, dt$$

MUST EQUAL THE *TOTAL* REQUIREMENTS

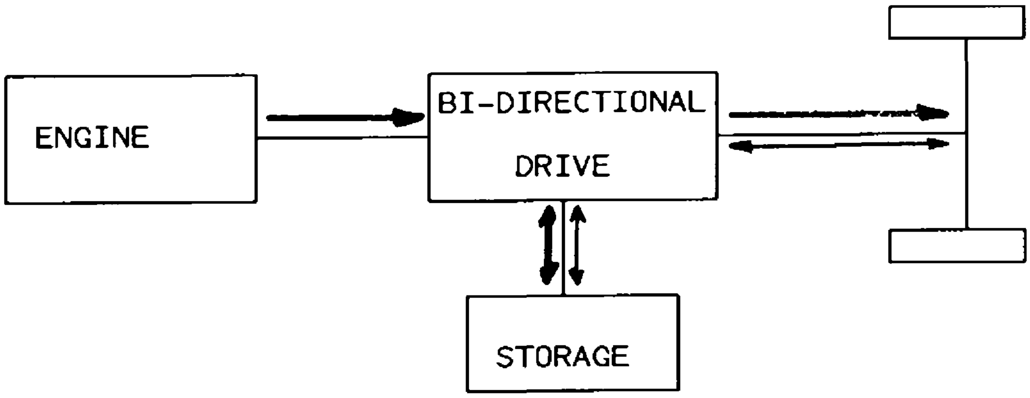
$$\int_0^T P_{vehicle}\, dt$$

OVER THE DRIVING SCHEDULE.

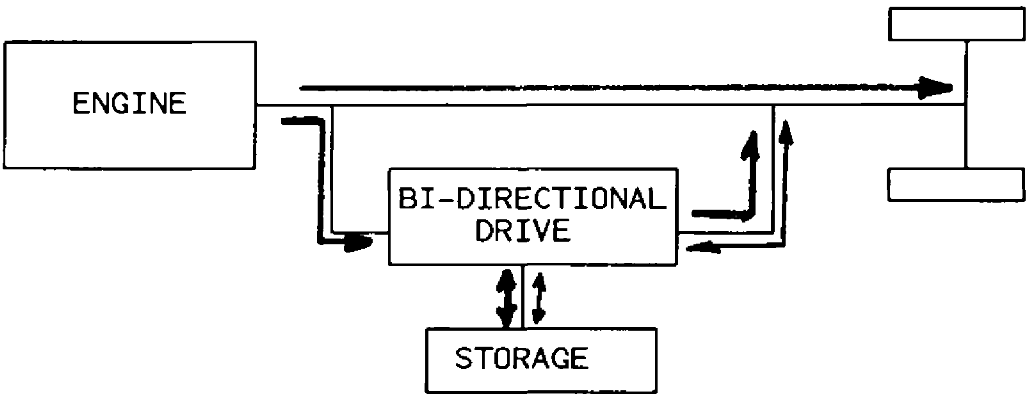
- THE ABILITY OF THE NON-PETROLEUM ENERGY STORGE DEVICE TO RE-USE VEHICLE KINETIC ENERGY CAN FURTHER REDUCE FUEL CONSUMPTION

HYBRID VEHICLE ARRANGEMENTS

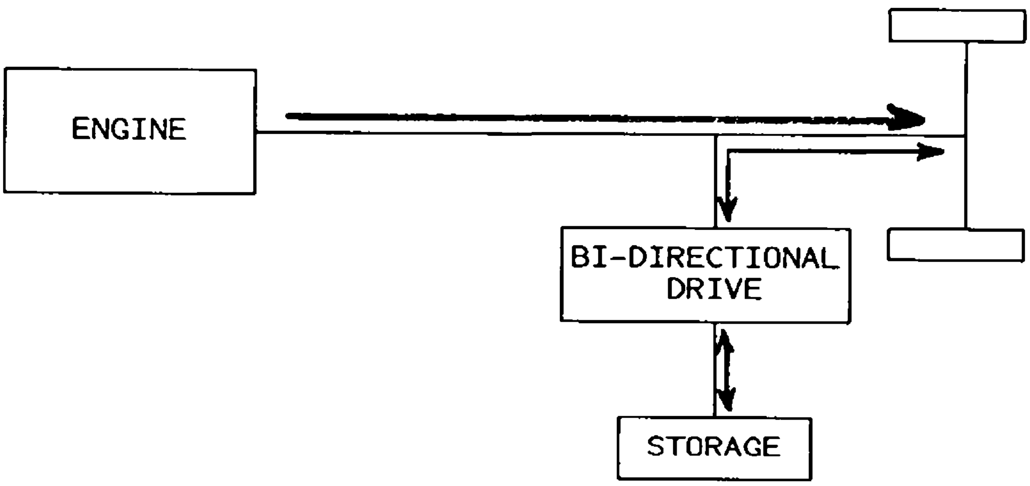
SERIES



PARALLEL



LIMITED PARALLEL (ASSIST)



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EACH OF THESE PRESENTS UNIQUE
RESEARCH OPPORTUNITIES

- **Component Technology**
- **Energy Management Strategy**
- **Dynamics & Control**

FREEDOM PROJECT FOCUS

FREEDOM HAS FOCUSSED ON BATTERY-ELECTRIC HYBRIDS BECAUSE

- OF THE POTENTIAL FOR ZERO TAILPIPE EMISSIONS IN URBAN DRIVING
- ENERGY STORAGE CAPABILITY IS HIGHER THAN OTHER CANDIDATES

  Hydraulic: 3.5 Wh/kg

  Pneumatic: 9 Wh/kg

  Low-Tech Flywheel: 7 Wh/kg

  High-Tech Flywheel: 22 Wh/kg

  Pb-Acid Battery: 35 Wh/kg

  Ni-Zn Battery: 50 Wh/kg

FREEDOM PROJECT FOCUS, Continued

- GM's MAGNEQUENCH TECHNOLOGY INCREASES EFFICIENCY OF ELECTRIC MOTORS/GENERATORS
- DEMAND FOR ELECTRICAL POWER IN CONVENTIONAL AUTOMOBILES IS EXPECTED TO INCREASE
- DISTRIBUTED ELECTRICAL POWERTRAIN COMPONENTS INCREASE PACKAGING FLEXIBILITY

MOTIVATION

LONG-TERM RESEARCH ON VEHICLE ASPECTS OF GREENHOUSE PROBLEM

NEED FOR UNIQUE PRODUCT WITH FUNCTIONS PECULIAR TO ITS CONCEPT

Zero Tailpipe Emissions
No Range Limitation

IMPROVED FUEL ECONOMY AND EMISSIONS

(Load-Leveling and Regenerative Braking)

PAST AND PROJECTED INCREASES IN VEHICLE ELECTRICAL LOADS

IMPROVED ELECTRICAL COMPONENT TECHNOLOGY

POTENTIAL FOR IMPROVED HANDLING THROUGH INDIVIDUAL-WHEEL TORQUE CONTROL

FREEDOM PROJECT OBJECTIVES

- *DEFINITION OF AN "OPTIMUM" POWERTRAIN ARCHITECTURE (Under New Constraints)*

  - **Improved Exhaust Emissions and Fuel Economy**
  - **All-Electric Operating Mode**
  - **Flexible Packaging Possibilities**
  - **Independent 4-Wheel Electric Drive Capability**

- *ACCELERATED DEVELOPMENT OF HIGH-PERFORMANCE BATTERIES*

(

- *DEFINITION OF A NEXT-GENERATION AUTOMOTIVE ELECTRICAL SYSTEM*

  Higher System Efficiency
  Increased Power
  Multiple Voltages Available

TECHNICAL APPROACH

- *ADDRESS THE MAJOR FEATURES OF THE FREEDOM CONCEPT IN PARALLEL*

    - **Propulsion System**
    - **Accessory Energy Management Strategy**
    - **Independent Wheel-Torque Control**

- *EVALUATE ALTERNATE CONFIGURATIONS*

    - **Powertrain Arrangement**
    - **Vehicle Class**

- *BLEND THE TECHNOLOGY DEVELOPMENTS IN A FREEDOM CONCEPT VEHICLE*

    - **Flexible Packaging**
    - **Excellent Aesthetics**

THE FREEDOM CONCEPT

- *DISTRIBUTED POWERTRAIN COMPONENTS*

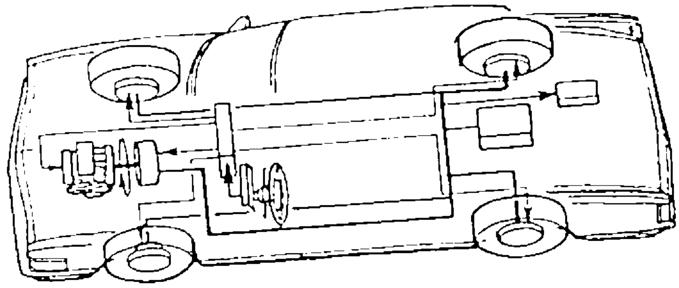
- *DUAL-MODE OPERATION*

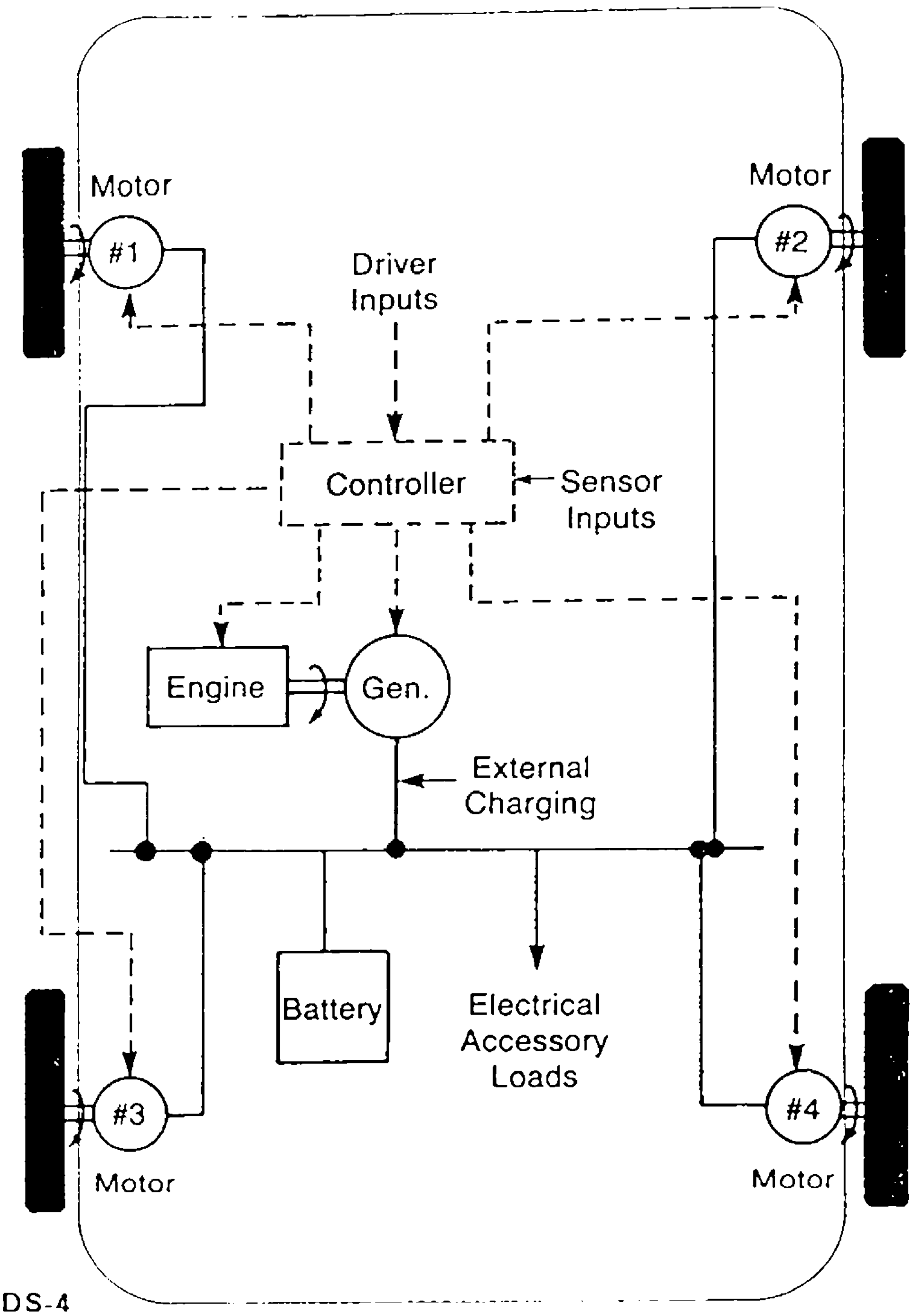
    - **All-Electric**
    - **Hybrid**

- *ELECTRIC-TRANSMISSION POWERTRAIN FEATURING*

    - **IC Engine Operating at Constant Speed and Load**
    - **Advanced Batteries for Load-Leveling**
    - **Up to Four Sunraycer-Type Drive Motors**

- *MULTIPLE VOLTAGE LEVELS TO SUPPLY ACCESSORY POWER*





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N-CAR SIMULATION

TEST MASS	1418 kg
ROLLING RESISTANCE COEFF.	0.009
DRAG COEFFICIENT	0.362
FRONTAL AREA	1.97 sq m

DRIVE TRAIN

TRANSMISSION	-69 kg
ENGINE (LESS 1 CYL)	-32 kg
ALTERNATOR	27 kg
RECTIFIER	14 kg
BATTERIES	255 kg
INVERTERS	49 kg
MOTORS	48 kg
WIRING	77 kg

NET CHANGE	369 kg

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HYBRID POWERTRAIN N-CAR SIMULATIONS

FUEL ECONOMY

	Urban	Highway
N-CAR MEASUREMENT	23.6	37.5
HYBRID (zero acc. load)	34.7	43.2
HYBRID (1 KW acc. load)	29.8	39.

TAILPIPE EMISSIONS

	HC[1]	CO[1]	NOx[2]
N-CAR MEASUREMENT	.18	1.1	1.05
HYBRID (zero acc. load)	.08	.4	.85
HYBRID (1 KW acc. load)	.09	.47	1.0

1 – 90% Catalyst Efficiency 2 – 70% Catalyst Efficiency

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FREEDOM CONCEPT SIMULATION VEHICLE

TEST MASS	1050 kg
ROLLING RESISTANCE COEFF.	0.009
DRAG COEFFICIENT	0.250
FRONTAL AREA	1.5 sq m

DRIVE TRAIN MASS

ENGINE	23 kg
ALTERNATOR (15 kW)	16 kg
RECTIFIER (200 A)	8 kg
BATTERIES (60 Ah, 65 kW)	150 kg
INVERTERS (4 @ 225 A)	29 kg
MOTORS (4 @ 4 kW)	28 kg
WIRING	45 kg
TOTAL	299 kg

VEHICLE & PAYLOAD *751 kg*

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Advanced Delco Remy Ni-Zn Batteries

ALL-ELECTRIC RANGE

100% Initial State-of-Charge

	Miles	Final S-o-C
Zero Acc. Load	37.2	25%
1 kW Acc. Load	29.8	19%

HYBRID FUEL ECONOMY, mi/gal

	Urban	Highway
Zero Acc. Load	[illegible]	[illegible]
1 kW Acc. Load	[illegible]	[illegible]

HYBRID TAILPIPE EMISSIONS, gm/mi

	HC[1]	CO[1]	NO_x[2]
Zero Acc. Load	.09	[illegible]	.21
1 kW Acc. Load	.13	[illegible]	.29

1 – 90% Catalyst Efficiency
2 – 70% Catalyst Efficiency

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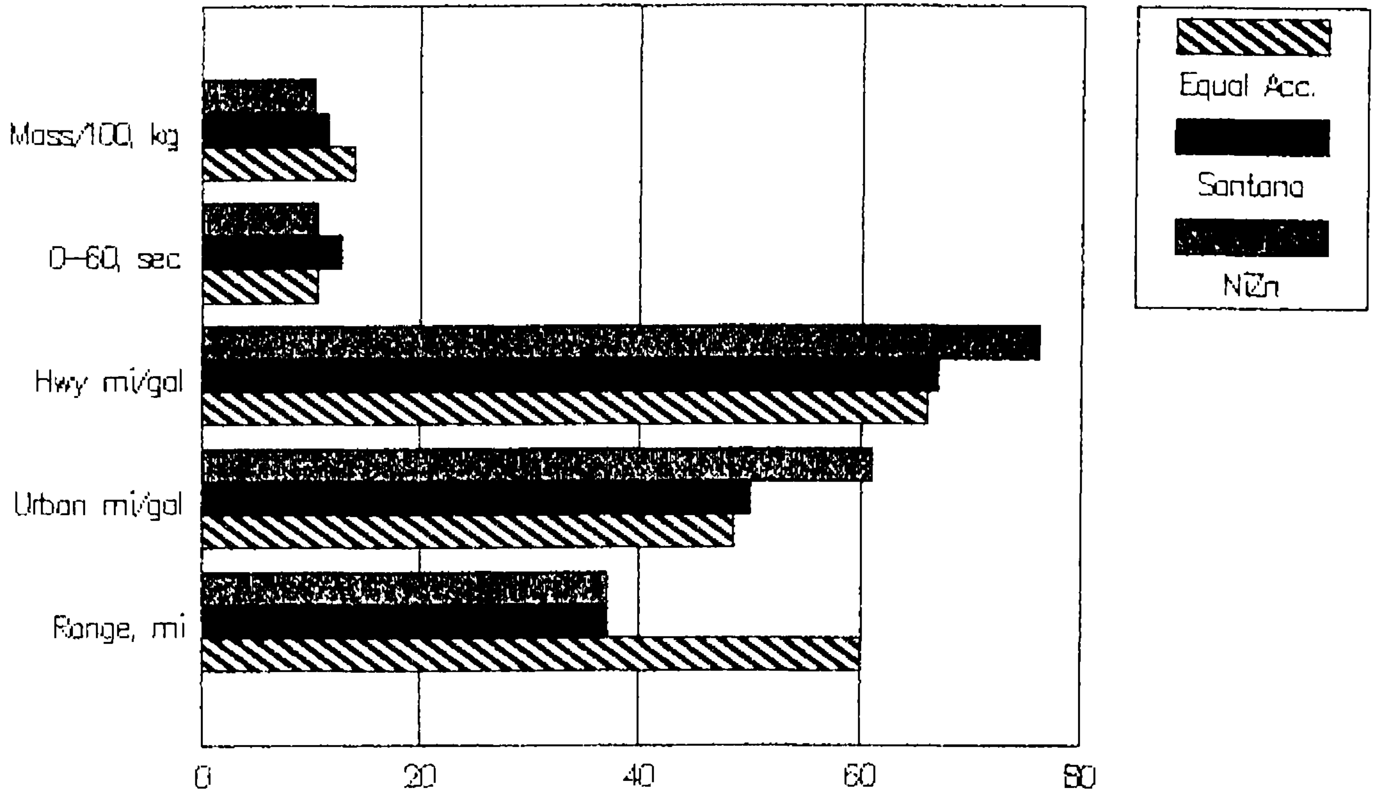
IMPACT OF BATTERY PERFORMANCE



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SUMMARY

- SIMULATIONS HAVE SHOWN THE FREEDOM CONCEPT TO HAVE POTENTIAL FOR ACCEPTABLE RANGE IN A ZERO-EMISSIONS MODE, AND LARGE REDUCTIONS IN EMISSIONS WITH IMPROVED FUEL ECONOMY IN THE HYBRID MODE.

- THE VEHICLE PERFORMANCE WILL DEPEND ON AVAILABLE BATTERY TECHNOLOGY.

- OTHER POWERTRAIN ARRANGEMENTS AND VEHICLE CONFIGURATIONS NEED TO BE INVESTIGATED.

Kopien: Dr. Schubert J. Kirschner
A. Bambels
R. Schmidt
G. Polz

Inter-Organization

GM

General Motors Research Laboratories
Warren, Michigan 48090-9055

DATE: July 25, 1989

SUBJECT: IC Engine/Battery Electric Hybrid Vehicles

TO: Dr. P. Bausch, Staff Engineer
Advanced Chassis, Transmission and Drivetrain
Adam Opel AG

I enjoyed talking with you last week, particularly in learning about your early experience with the hybrid electric drive vehicle. Some of the operational problems you describe can only be dealt with on a real vehicle. We would appreciate any data on the performance of this vehicle which you could send to us. It would be very helpful in qualifying our parallel-hybrid simulation code which we expect to receive in October.

I am enclosing a copy of our presentation to the GM Science Advisory Committee given in January of this year. These charts describe what we hope to accomplish in the Freedom project. The estimated fuel economy and tailpipe emissions charts are for illustrative purposes only in that the concept vehicle has changed since then and the simulation program has been updated with current engine data. However, we still estimate over 20% improvement in Urban fuel economy with the series hybrid concept. I have also included a cross-section of our in-wheel motor and drive concept which is planned for all four wheels, including the front steering wheels. We do not plan to employ four-wheel steer in the first vehicle but do not see any reason why it could be incorporated later.

I should remind you that Mr. Gary Dickinson has imposed a high degree of security on the Freedom project and we are discussing it only with those areas of General Motors who exhibit a "need to know." However, we look forward to the benefit of your experience as we explore methods of working together on hybrid concepts.

Gerald D. Skellenger

Gerald D. Skellenger
Project Manager
Trilby Vehicle Systems Department

cc: M. M. Kamal
R. D. Fruechte