ΝΟΤΙΟΕ

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PHASE I OF THE NEAR TERM HYBRID PASSENCER VEHICLE DEVELOPMENT PROGRAM

(NASA-CR-163224)PHASE 1 OF THE NEAR TERMN80-28250HYBRID PASSENGER VEHICLE DEVELOPMENTPROGRAM. APPENDIX B: TRADE-OFF STUDIES.UnclasVOLUME 2:APPENDICES Final Report (FiatUnclasResearch Center)51 p HC A04/MF A01G3/8522367

FINAL REPORT

APPENDIX B: TRADE-OFF STUDIES

Volume II: Appendices

Prepared for JET PROPULSION LABORATORY

bу

CENTRO RICERCHE FIAT S.p.A. Orbassano (Turin) - ITALY



The research described in this publication represents the second of the several Tasks of the "Phase I of the Near Term Hybrid Passenger Vehicle Development Program" being carried-on Centro Ricerche FIAT (CRF) on Contract No. 955187 from the Jet Propulsion Laboratory, California Institute of Technology.

Turin, June 15, 1979

This Report, prepared by:

M. Traversi and R. Piccolo of CRF

has been issued in conformance to the following specifications:

JPL Contract No. 955187 Exhibit No. II, Dec. 1, 77 Contract Documentation – Phase I Data Requirement Description No. 2

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APPENDIX A.3-1 - "SPEC 78" Computer Simulation Model

The mathematic model in the object (SPEC '78) was implemented in 1978 to provide a powerful design tool for the evaluation of performance consumption and emissions of any type of vehicle using any combination of components in the propulsion system.

The model can now simulate the most common propulsion systems but was designed in such a way that the simulation of any new propulsion system can be easily added to the basic program.

The program consists of mathematic simulations of any vehicle component and external environment effects: internal combustion engine, transmission, automatic transmission, differential, rear-axle ratio, electric motors and controls, batteries performances, aerodynamic drag, rolling resistance etc. An appropriate code is used to identify any specific propulsion system consisting of a given configuration made of specific components. A second identification code is used to label the system control logic.

The model, on the basis of input design parameters, calculates the vehicle performance parameters on a time base related to given initial operating condition.

The time base is made of a sequence of discrete time steps cycle points of the simulated mission which can be varied from 1 ms to 1 s.

The traveled distance is then obtained as the integral of the speed vs/ time function.

The program input data consists of vehicle code, propulsion system code and mission parameters. The program output data consists of performance, consumptions and emissions achieved in the mission. The program is also able to show the efficiency breakdown at component level.

The values of any variables under evaluation, if required, can also be given at intervals not longer than 1 second.

The mathematic simulation used by CRF was validated by other calculation methods and experimental data for conventional propulsion, hybrid $^{(1)}$ and electric vehicles.

(1) See Ref. [1], Subsection 1.2, Vol. I.

- 1 Heading
- 2 Configuration block diagram
- 3 Main vehicle parameters
- 4 Lead-Acid batteries map
- 5 Overall batteries data

6 Electric motor maximum power characteristics

7 Paramaters for electric motor simulation

8 Current maximum values

- 9 Magnetization curves map
- 10 Parameters for the internal combustion engine simulation
- 11 Power and torque force characteristics of the internal combustion engine
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- 24 Table of Total energy necessary in one cycle
- 25 Table of Electric energy
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6.07 1.23 3397.56 1171.11 8.17.43 5117.43 1116.43 8.75 5117.43 1116.43 8.75 5117.43 1116.43 8.75 5117.43 1116.43 8.75 5117.43 1116.43 8.75 5117.43 1116.43 8.75 5117.43 1116.43 8.75 5117.43 1116.43 8.75 5117.45 11116.43 8.75 5117.45 11116.43 8.75 5117.45 11111.41 8.75 7.75 7.75 8.75 7.75 7.75 8.75 7.75 7.75 8.75 7.75 7.75 8.75 7.75 7.75 8.75 7.75 7.75 8.75 7.75 7.75 8.75 7.75 7.75 8.75 7.75 7.75 8.75 7.75 7.75 8.75 7.75 7.75 8.76 7.75 7.75 8.74 7.75 7.75 8.74 7.75 7.75 8.74 7.75 7.75 8.74 7.75 7.75 8	6.07 1.23 3396.56 17.43 11011.14 7.50 517.43 11011.43 11011.44 7.50 565 3449.56 117.43 11011.44 7.50 561 37248.11 1937.66 7.50 561 37248.11 1937.66 7.51 517.43 1101.14 997.66 7.51 517.43 1101.14 997.66 7.51 517.64 1111.64 975.76 11.00 7.57 775.76 1111.11.16 7.45 11.68 7.57 1177.64 7.45 11.64 7.55.76 1111.11.16 7.45 1.55.76 1111.11.16 1775.76 7.45 7.55.76 1111.11.16 1775.76 7.45 7.55.76 11775.76 11775.76 7.45 7.55.76 11775.76 11775.76 7.45 7.55.76 1775.76 11775.76 7.45 7.55.76 1.775.76 11775.77 7.57	5	7.09		2948.22	1611.35	1513 87
4.98 5.95 5117.43 11116.43 5.973.51 565 34549.74 1913.65 7.95 5117.43 11116.43 7.95 5117.43 11116.43 7.95 5117.43 11116.43 7.95 545.49.74 1913.65 7.91 7.91 7.91.11 7.91 7.91 7.91.11 7.91 7.91 7.91.11 7.92 7.91 7.91.11 7.93 7.95.77 1177.41 7.93 7.55.77 1179.27 7.93 7.55.77 1177.41 7.93 7.55.77 1177.41 7.93 7.55.77 1177.41 7.93 7.55.77 1179.27 7.93 7.55.77 1177.41 7.93 7.55.77 1177.41 7.93 7.55.77 1177.41 7.93 7.55.77 1179.27 7.93 7.55.77 1177.41 7.94 5.94.72 1177.41 7.94 5.94.42 5.94.42 7.95 5.	4.98 5.95 6117.43 11116.43 5.973 55749.74 1913.63 613 5535.61 7708.11 1913.63 7.95 6117.43 11116.43 11116.43 7.91 517.61 70 46 7.91 517.61 70 46 7.91 705.74 11116.43 9.75 7.39 275.78 11114.27 9.75 7.39 2764.53 11144.27 9.75 7.39 2764.53 11144.27 9.75 7.39 275.78 11144.27 9.75 7.39 1175.77 11775.41 9.75 1.54 554.77 11775.41 9.75 1.54 554.77 11775.41 9.75 1.457.77 11775.41 11775.41 9.75 1.414.77 11775.41 11775.41 9.75 1.414.77 11775.41 11775.41 9.75 1.417.77.75 11775.41 11775.41 9.75 1.457.77 11775.41 11775.41 9.75 1.414.72 </td <td>G</td> <td>J0"9</td> <td>1.23</td> <td>3390.56</td> <td>1117.17</td> <td></td>	G	J0"9	1.23	3390.56	1117.17	
3.97 51 37288.11 1933.55 1.50 .66 34549.75 11115.15 .75 .61 37288.11 1933.66 .75 .65 34549.75 11115.45 .75 .65 34549.75 11115.45 .75 .75 .75 1115.45 .75 .75 .75 .75 9.75 .75 .75 .75 9.75 .73 .75 .74 9.75 .73 .75 .74 9.75 .75 .75 .76 9.75 .75 .75 .76 9.75 .75 .75 .76 9.75 .75 .75 .76 9.75 .75 .75 .76 9.75 .75 .75 .777 9.75 .75 .75 .777 9.75 .75 .75 .777 9.75 .75 .75 .777 9.75 .75 .75 .777 9.75 .75 .75 .75 9.75 .75 .75 .777 19.77 .75 .75 .777 11.200 .75 .75 <td>3.97 5.0 5.0 5.0 5.0 5.0 5.0 1.50 .61 37298.11 1933.61 POTENZA .61 37298.11 1933.61 POTENZA .61 3726.53 1933.61 POTENZA .61 3726.53 1933.61 POTENZA .65 345.75 11116.43 POTENZA .65 345.75 11116.43 POTENZA .75 .75 11174.27 POTENZA .75 .78 11174.27 POTENZA .73 .78.73 11776.41 POTENZA .73 .78.73 11776.41 POTENZA .73 .78.43 11776.41 POTENZA .73 .78.43 11776.41 POTENZA .73 .78.43 11776.41 POTENZA .73 .78.43 11777.41 POTENZA .74 .73.356.78 11777.41 POTENZA .74 .73.356.78 11777.41 POTENZA .74 .73.356.78 11777.41 POTENZA .74 .73.3156.73 11777.41 POTENZA .74 .73.3156.73 11777.41 POTENZA .74 .73.44 .7776.41</td> <td>5</td> <td>4.96</td> <td>50</td> <td>6117 43</td> <td></td> <td></td>	3.97 5.0 5.0 5.0 5.0 5.0 5.0 1.50 .61 37298.11 1933.61 POTENZA .61 37298.11 1933.61 POTENZA .61 3726.53 1933.61 POTENZA .61 3726.53 1933.61 POTENZA .65 345.75 11116.43 POTENZA .65 345.75 11116.43 POTENZA .75 .75 11174.27 POTENZA .75 .78 11174.27 POTENZA .73 .78.73 11776.41 POTENZA .73 .78.73 11776.41 POTENZA .73 .78.43 11776.41 POTENZA .73 .78.43 11776.41 POTENZA .73 .78.43 11776.41 POTENZA .73 .78.43 11777.41 POTENZA .74 .73.356.78 11777.41 POTENZA .74 .73.356.78 11777.41 POTENZA .74 .73.356.78 11777.41 POTENZA .74 .73.3156.73 11777.41 POTENZA .74 .73.3156.73 11777.41 POTENZA .74 .73.44 .7776.41	5	4.96	50	6117 43		
1.55 61 37208.11 1911.65 . 61 37208.11 1911.65 61 37208.11 . 61 37208.11 61 37208.11 1911.65 . 61 3736.14 61 3736.14 101 . 61 3736.14 61 3736.14 101 . 7 . 7 . 7 . 7 111.64 101 0.75 . 7 . 15 6601.34 1913.65 11 9.75 . 7 . 15 7.53 1111.65 11.66 0.75 . 7 . 155.78 1111.65 1111.12 0.75 . 7 . 155.78 1111.22 0.75 . 75 . 1775.73 11775.73 0.75 . 75 . 75 . 75 11775.73 1.77 . 72335.71 11775.73 11775.73 1.77 . 72335.73 11775.73 11775.73 1.6 . 735.74 . 73336.11 735.745 1.77 . 72335.74 177	1.50 61 37308.11 1933.60 61 37308.11 933.60 11 1933.60 61 37308.11 61 37308.11 1933.60 61 37308.11 61 37308.11 1933.60 61 37308.11 60 349.75 11 70 7 7 7 7 7 7 7 1100 7.3 2.12 6.601.34 1935.78 11 9.75 7.73 7.73 7.74 7.74 7.74 9.75 7.73 7.74 7.3155.76 11775.41 9.75 7.73 7.75 7.75 7.75 7.1775.71 1775.71 1777.71 1777.71 7.1775.71 1775.71 1777.71 1777.71 7.178 7.35 7.35 7.35 7.35 7.178 7.333 7.75 7.75 7.75 1101 7.01 7.01 7.01 7.75	6	36.80		12.1.40		
POTENZA CNUSUHO CO HC POTENZA CNUSUHO PPH PPH POTENZA CNUSUHO CO HC POTENZA CNUSUHO CO PPH POTENZA POTENZA PPH PPH POTENZA PPH PPH PPH POTENZA POTENZA PPH PPH POTENZA POTENZA PPH PPH POTENZA POTENZA POTENZA PPH POTENZA POTENZA	Ротемил Б. 37268.11 1933.65 Ротемил Соч ККБ/Ч) РРЧ ЧС 12.01 3.15 2.33 2764.56 1131.218 2.15 1.45 3.755.78 1131.218 27 2.15 1.45 3.755.78 1131.218 27 2.15 1.45 3.755.78 11779.218 2.15 1.45 3.755.73 11777.611 2.15 1.45 3.755.73 11777.611 2.15 1.45 3.754.45 11777.611 2.15 1.45 3.453.73 11777.611 2.15 1.41 72.333 11777.611 2.15 3.4356.73 <td< td=""><td>5</td><td></td><td>99</td><td>14 91210</td><td></td><td></td></td<>	5		99	14 91210		
POTENZA COUSUHO CO HC CV (KG/H) PPH HC 12.01 3.12 Ka601.34 1065.41 12.03 1.54 355.78 1179.16 12.03 1.54 355.78 1179.16 2.15 1.59 1.54 355.78 1177.74 2.15 1.54 355.78 1177.91 2.15 1.54 355.78 1177.91 2.15 1.54 355.78 1177.91 2.15 1.54 355.78 1177.91 11.78 3.55.78 1177.91 1779.91 11.78 3.55.78 11779.91 11779.91 11.98 3.55 1.20 305.91 1779.91 11.98 3.55 1.20 372.59 11779.91 11.98 1.79 11779.91 11779.91 11.98 1.20 10925.91 1279.91 11.98 1.20 10927.44 1279.91 11.98	POTENZA CDU-SUMO CO HC CV (KG/H) PPH PPH 12.01 3.15 (KG/H) PPH 12.03 1.54 5355.78 1173.27 2.35 1.54 5355.78 1173.27 2.35 1.54 53430.73 1174.27 2.35 1.54 3356.73 1173.27 2.35 1.54 35430.73 1173.27 2.35 1.41 775.41 11775.41 2.15 1.45 3356.17 11775.41 2.15 1.41 775.41 11775.41 2.15 1.45 3356.43 11775.41 2.15 1.41 775.41 11775.41 2.15 1.41 72.33 11775.41 11.45 2.41 72.33 1279.59 11.45 2.41 72.33 </td <td>ci</td> <td>5.</td> <td>19</td> <td>37208.11</td> <td>1937.68</td> <td>17.16</td>	ci	5.	19	37208.11	1937.68	17.16
POTENZA CNUSUMO CO HC WUN CV (KG/H) PPH	POTENZA CDUSUMO CO MC MUX CV (KG/H) PPH						
РОТЕМИХА СПИ:SUMO ГО РРН РРН РРН РРН РРН РРН РРН РРН РРН РР	РПТЕМТА СПИ:SUMO ГО НС МОН 12.91 3.15 (4601.34 1965.41 214 11.60 2.39 2764.53 1172.17 9.75 2.77 3155.78 1131.16 7.9 375 735.73 11772.41 299 7.45 11.59 3755.73 11772.41 1995 7.9 11.54 5355.73 11772.41 1995 7.9 11.54 5355.73 11772.41 1995 7.9 11.64 3545.73 11772.41 1995 7.9 11.64 3545.73 11772.41 1995 7.9 11.64 3545.73 11772.41 1995 7.9 11.74 5345.73 11772.95 147 15.71 3.524.41 72335.73 11770.95 147 15.71 3.524.42 1934.61 193 15.71 1.76 5945.78 11375.99 147 11.94 2.46 5945.48 11334.11 1915 15.72 3.57 62112.77 1798.46 1932 15.71 1798.46 1932 15.71 1798.46 1932 15.71 1798.46 1932 15.71 1798.46 1932 15.57 62112.77 1798.46 1932 15.55 1.41 1925.41 1269.23 15.55 1.41 1925.41 1269.23 15.55 1.41 1925.41 1269.23 15.55 1.41 1925.41 1269.25 15.55 1.57 1126.99 15.51 15.53 2.66 7497.23 15.51 15.53 2.61 1259.25 15.51 15.51 1259.25 15.51 15.51 1259.25 15.51 12.50 1991.72 15.51 15.51 1259.52 15.51 12.50 1991.72 15.51 12.50 1991.72 15.51 15.51 1259.52 15.51 12.50 1991.52 15.51 12.50 1991.52 15.51 12.50 15.51 12.50 15.50 11.50 15.51 12.50 15.51 12.50 15.50 12.50						
CV (KG/H) PPH PPH PPH PPH 12.01 3.1% K6001.34 1065.41 214 9.75 2.33 2764.55 1111.42 214 9.75 1.59 3.155.76 1131.16 1599 9.75 1.59 355.76 1131.16 1599 9.75 1.59 355.76 1133.24 1996 8.35 1.59 1.54 35430.73 11775.01 206 2.15 1.51 3.2430.73 11775.01 206 2.15 1.54 35430.73 11775.01 206 2.15 1.54 35430.73 11775.01 206 2.16 3.54 3250.59 11775.01 206 2.16 3.54 3250.59 11775.01 206 11.00 00 00 00 00 11.01 01 00 00 01 11.01 01 01 01 01 11.01 01 00 01 01 11.01 01 00 01 01 11.01 01 00 01 01 11.01 01 01 01 <	CV (KG/H) PPH PPH </td <td></td> <td>PUTENZA</td> <td>CONSUME</td> <td></td> <td>NC NC</td> <td></td>		PUTENZA	CONSUME		NC NC	
12.01 3.1% 6601.34 1065.41 219 9.75 2.39 2764.55 11184.27 199 9.75 2.39 2764.55 11184.27 199 9.75 7.93 1.54 5535.73 1184.27 199 4.5 1.54 5535.73 11775.41 199 199 4.35 1.54 5535.73 11775.41 199 149 2.15 1.54 5535.73 11775.41 199 149 2.15 1.64 3353.73 11775.41 147 166 2.15 1.64 3353.73 11775.41 147 166 2.15 1.64 3353.73 11776.93 1177 36 37 2.16 1.67 3.24 349 37 374 37 374 37 37 37 37 36 37 36 37 36 37 36 37 37 37 37 37 37 37 37 37 37 37 37 37 37 37	12.01 3.15 f.4601.34 1065.41 215 9.75 2.39 275.75 1134.27 1995 9.75 2.39 275.75 1131.15 159 9.75 2.35 1.54 5535.73 1184.27 1995 9.75 2.35 1.54 5535.73 1184.27 1995 9.75 1.54 5535.73 1795.76 1131.75 779 9.75 1.59 11.457.12 1775.71 1775.71 1995 9.75 1.53 11.615 11437 1975.61 131 9.75 1.53 11.6471 34305.75 11776.71 376 9.75 1.67 3.24 34305.75 11776.71 376 9.75 1.67 3.24 34505.31 11776.71 9.74 11.76 9.74 1776.93 1167 11.76 9.74 1776.93 11917 1915 11.76 9.74 1776.93 11917 1915 11.76 9.74 1776.93 11779.93 1167 11.76 9.74 1795.461 1917 1917 9.65 1.26 9.93.93 11917 1916 9.65		2	(KG/H)	Hdd	Hdd	-idd
11.00 2.39 764.54 50 1184.27 299 9.75 2.39 764.56 1313.74 1996 9.75 2.15 1.54 555.76 1313.74 1996 4.35 1.54 555.75 11456.17 1775.01 306 4.35 1.54 555.75 11456.17 1775.01 306 2.15 1.54 555.75 11456.71 306 313.74 2.15 1.64 3.55.75 11456.71 306 2.15 1.64 3.5436.75 11775.01 306 2.15 1.64 3.5436.75 11775.01 306 2.15 1.64 3.5436.33 11775.01 306 2.16 732.40 733.41 733.41 306 15.71 2.44 733.81 133.81 145 15.71 2.45 732.42 994.64 612 15.71 7.45 732.44 133.81 145 15.71 7.45 732.44 1776.46 157 15.75 1.46 1997.44 1776.46 33.14 15.75 1.46 1999.33 1177 1796 15.65 1.46 1999.74	11.00 2.39 764.56 1184.27 1996 9.75 2.75 1.54 5535.73 1755.76 1133.74 9.75 2.15 1.54 5535.73 1775.71 1996 4.55 1.54 5535.73 1775.71 1996 4.55 1.54 5535.73 1775.71 1996 4.55 1.54 535.73 1775.71 1996 2.15 1.64 33557.73 11775.71 1996 2.15 1.64 33557.73 11775.91 1996 2.15 1.64 33557.73 11775.91 1996 2.15 1.64 33557.73 11775.91 1996 2.45 5945.33 1378.91 1993 1997 15.71 3.24 72335.78 1977.93 1477 15.71 3.24 723.47 2945.46 1237 15.71 3.24 723.47 2945.46 2318 15.71 3.24 723.47 2945.46 2318 15.71 1.75 31778.97 11778.93 1451 15.71 1.27 1297.41 17796.46 2318 15.72 1.27 1796.45 2318 <t< td=""><td>5</td><td>0</td><td></td><td>. 6.11.4</td><td></td><td></td></t<>	5	0		. 6.11.4		
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This Appendix provides a description of the Configuration alternatives as presented in our Proposal with the exclusion of the series configuration not even taken into consideration during the Trade-off Studies because of its less fuel-efficient operation.

In all parallel configurations the engine power is applied directly to the drive wheels and the power handled by the reversible electric machine (electric motor-generator) can be added or subtracted as appropriate.

The interconnection between the two machines can be accomplished using various mechanical configurations which have the function of uncoupling or altering the speed ratios with respect to one another and relative to the wheels and can always be represented in the block diagram shown on Figure A.3-2.1, as Subsystems No. 1, 2 and 3.

The simplest layout is shown on Figure A.3-2.2; Subsystem No. 1 merely consists of a clutch, Subsystem No. 2 includes a reduction gear unit between motor and engine, while Subsystem No. 3 is not required.

An improvement of the previous system is shown in Figures A.3-2.3 and A.3-2.4 where a Continuously Variable Ratio Transmission (CVRT) is introduced in Subsystems No. 3 and No. 1 respectively.

Obviously, the introduction of a more complex mechanical component such as the CVRT increases the vehicle cost but significantly improves system performance and efficiency.

The Trade-off Studies must therefore determine whether the cost increase is justified by a significant improvement.

The choice between the two configurations using a CVRT is not significantly tied to economic constraints as much as to the following technical considerations.

In the case of the CVRT placed immediately upstream of the rear axle (Configuration No. 2), all the power supplied to the wheels, which is the sum of thermal and electric power, is handled by the transmission under optimal conditions. The same applies to the braking energy which, thanks to the stepless transmission, may be recovered at rotational speeds corresponding to high motor efficiency. The CVRT, on the other hand, must be capable of handling a higher torque being this requirement associated with a more difficult coupling between the engine and the motor owing to fixed ratio

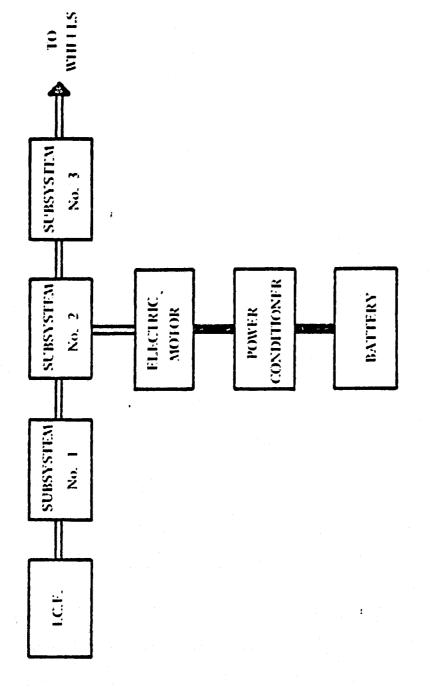


FIG. A.3-2.1 - HYBRID VEHICLE POWERTRAIN: PARALLEL CONFIGURATION

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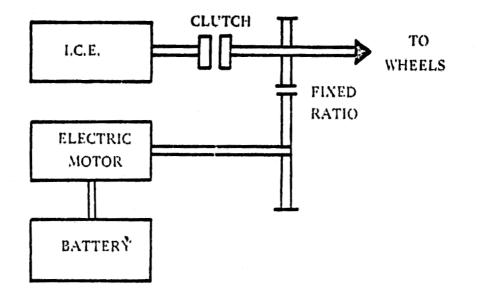
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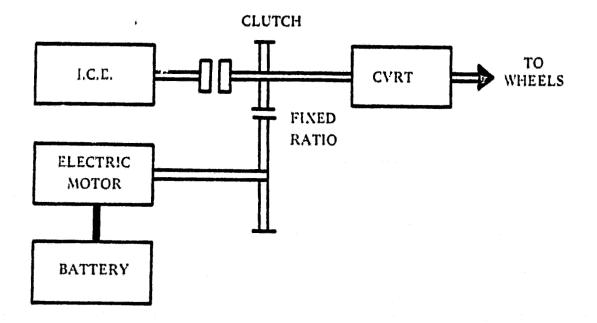
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FIG. A.3-2.2 - HYBRID VEHICLE: PARALLEL CONFIGURATION No. 1



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FIG. A.3-2.3 - HYBRID VEHICLE: PARALLEL CONFIGURATION No. 2

A.3-34

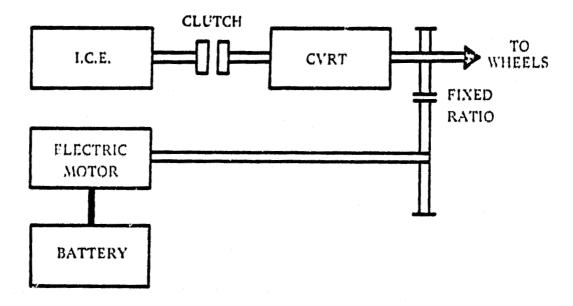


FIG. A.3-2.4 - HYBRID VEHICLE: PARALLEL CONFIGURATION No. 3

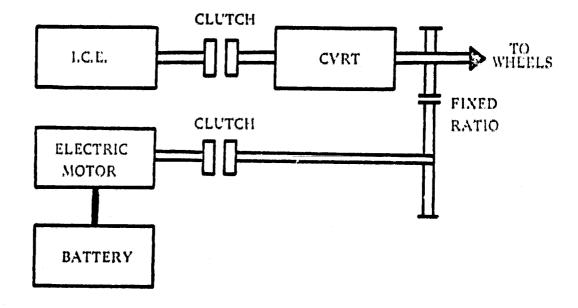
existing between the two.

In the case of Configuration No. 3, where the CVRT is placed on the engine output shaft upstream of the fixed ratio, less severe operating conditions and ratings are required for the CVRT while the coupling between the motor and the engine becomes much more flexible and provides therefore the possibility of a wider choice of components. In this case however only the engine power is delivered to the wheels in optimum conditions and the recovery of the braking energy is less efficient occurring at motor rotational speeds imposed by the wheel speed and by the selected fixed ratio.

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A variant may be introduced on the three above configurations by introducing a clutch between the motor and the fixed ratio. For the sake of simplicity, since the same clutch could be used in any configuration, only the case where the clutch is introduced in Configuration No. 3 will be considered as shown on Figure A.3-2.5.

The function of this clutch is to isolate the motor from the drive train when only the engine thermal power is used or required so that the energy corresponding to the inechanical loading effect of the electric motor can be saved.



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FIG. A.3-2.5 - HYBRID VEHICLE: PARALLEL CONFIGURATION No. 4

APPENDIX A.3-3 - Lead-Acid and Na-S Traction Batteries

The battery and the electric propulsion system of the H.V. will be analyzed in greater details during the preliminary design. This Appendix provides some preliminary assessments on the fundamental characteristics of the only two types of traction batteries that have been evaluated during the Trade-off Studies: Lead-Acid and Sodium-Sulphur. The Lead-Acid type is characterized by a low initial cost, is already available on the market and is susceptable of some technological improvements. The Sodium-Sulphur type offers much higher specific energy but, as a product, it is still under development and therefore, while susceptable of significant technological improvement, its product availability by 1985 has yet to be validated. The main characteristics of the selected batteries are shown in Table A.3-3.1: they can be assumed as representative of the foreseable performance range.

A.3-3.1 Lead-Acid Batteries

The maximum available power at a given time is function of the average discharge power and of the total energy supplied to the load as shown in Fig. A.3-3.1 Assuming vehicle operation in the electric mode only, the vehicle range capability can be calculated as follows. The battery average discharge power is given by

$$\overline{W} = \frac{q \cdot v}{M_b}$$

where:

q is the vehicle average energy consumption

v is the vehicle average speed

M_b is the battery weight

The selected maximum power allows to determine, for a given \overline{W} , the specific energy (E) supplied by the battery. The vehicle range is then calculated by means of

$$R = \frac{E \cdot M_{b}}{q}$$

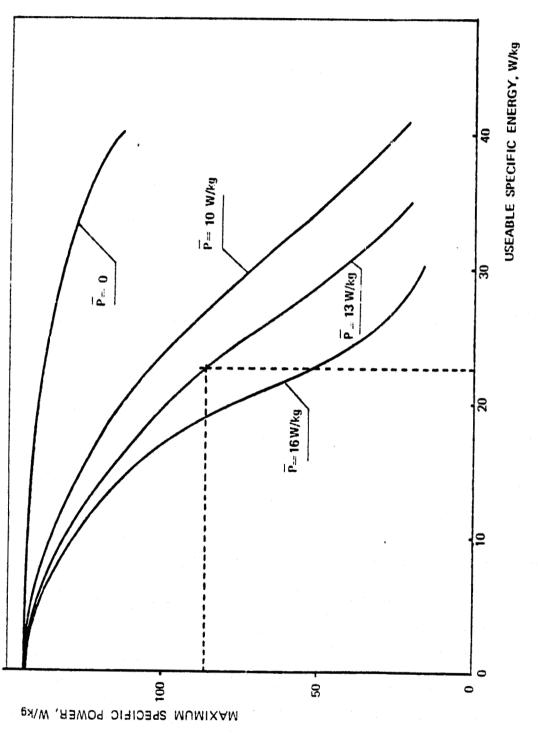
A.3-38

TABLE A.3-3.1

TRACTION BATTERIES CHARACTERISTICS

PARAMETER	LEAD-ACID	SODIUM-SULPHUR
OPEN CIRCUIT VOLTAGE, V	144	144
DISCHARGING VOLTAGE, V	144-110	144.72
CAPACITY (5 h), Ah	100	315
MAX DISCHARGING CURRENT, A	250	450
RECHARGING CURRENT (4 h), A	25	78
CURRENT EFFICIENCY: Ah _{out} /Ah _{in} POWER EFFICIENCY Wh _{out} /Wh _{in}	> 0.9 ≥ 0.7	1 Function of operating conditions
NUMBER OF ELEMENTS	12	432 (12 x 36)
SIZE, mm	775 x 830 x 300	794 x 976 x 400
WEIGHT, kg	300	300
OPERATING TEMPERATURE	ambient	300 - 350 ℃
LIFE CYCLES	400 to 800	300 to 900
MAINTENANCE FREQUENCY, mounths	6	6
COST, S	1,000	3,000
COST OF MAINTENANCE, Siyear	80	50

A.3-39





Considering a 5 hour discharge time in a hybrid propulsion system, the maximum energy that can be drawn from the battery corresponds to 80% of the stored energy. For the 1985 Lead-Acid batteries the expected specific energy is about 40 Wh/Kg which, for a 300 Kg, battery, corresponds to a total energy availability of 12 KWh. However, at 30% discharge the available power is much lower than the power at full charge and therefore, to guarantee vehicle performance over the entire operating range, the maximum discharge must be limited to about 50% of the available Ah and the initial maximum power accordingly derated. The 1985 model batteries shall guarantee 400 discharge cycles but, if the specific energy is kept in the 33-36 Wh/Kg, a life-cycle above 800 can be expected.

On the other hand Lead-Acid batteries, at discharge levels below 80% have a rather small internal resistance and provide therefore reasonably high efficiency operation.

A.3-3.2 Sodium-Sulphur Batteries

The power that can be supplied to the load is a simple function of the discharge current (1):

$$W = (V_0 + RI) \cdot I$$

The maximum power available is then:

$$W_{max} = \left(\frac{V_0}{2}\right) \cdot \frac{1}{R}$$

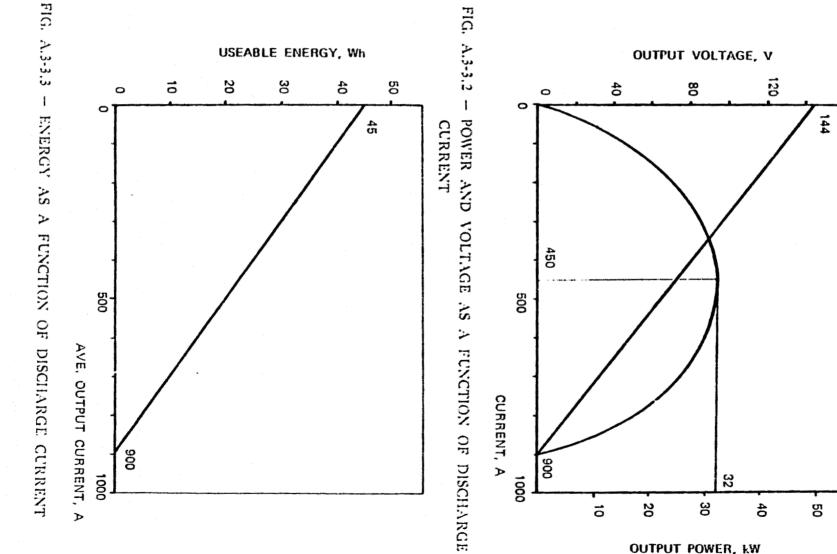
The total energy available from the batteries can be calculated as a function of the instantaneous discharge current as follows:

$$E = \int (V_0 - RI) \cdot I \cdot dt$$

and is therefore dependent on the vehicle speed vs/ time pattern. Considering a discharge at constant power the total available energy is given by:

$$E = C \cdot V = C \cdot (V_0 - RI)$$

where C is the battery capacity given by $C=/I \cdot dt$. The power and energy of the battery as a function of the discharge current are shown in Figures A.3-3.2 and A.3-3.3 Assuming a discharge depth of 80%, a life of 300 cycles is expected for Sodium-Sulphur batteries



OUTPUT POWER, kW

A. 3-42

presently produced is small series by the Brown Boveri Company. The technology is expected to improve significantly and a 600 cycle life is expected by 1985 which could reach 900 cycles by 1990.

The Sodium-Sulphur battery operates at a temperature between 300 and 350°C. If the temperature falls below the operating range, the β -allumina conductivity drops and all the reagents and reaction by-products solidify. For a 300 kg battery, 10 kWh per day are required to keep the battery at operational temperature, assuming that presently available insulation techniques are used. The battery heating energy is normally provided by the energy dissipated in the battery internal resistance during the charge/discharge cycles. In addition to the charge/discharge life, the Sodium-Sulphur battery also has a limited life in terms of cycles of thermal cooling below the normal operating range. The negative impact of thermal cooling on battery life is much more pronounced if cooling occurs at low charge levels because of damages induced to the ceramic component (β -allumina).

APPENDIX A.3-4 – FIAT Procedures and Regulation for mass production Cost estimates.

This Appendix provides a summary of the FIAT Procedures and Regulations as used by CRF to evaluate the production cost of a new vehicle which a mass production of above 1,000 - 1,500 units/day is planned for. This procedure could not be thoroughly used during the Trade-off Studies due to the limited design definition of the various vehicle components: the actual cost analysis was therefore based on the production cost of actual vehicle parts and components similar to those itemized but not defined at the manufacturing level for the hybrid vehicle conceptual design to be further developed during the Preliminary Design task.

A.3-4-1 Vehicle Breakdown

As a first step all the vehicle parts and components are broken down into four main categories or "assemblies":

- Engine and Transmission

– Chassis

Body Frame

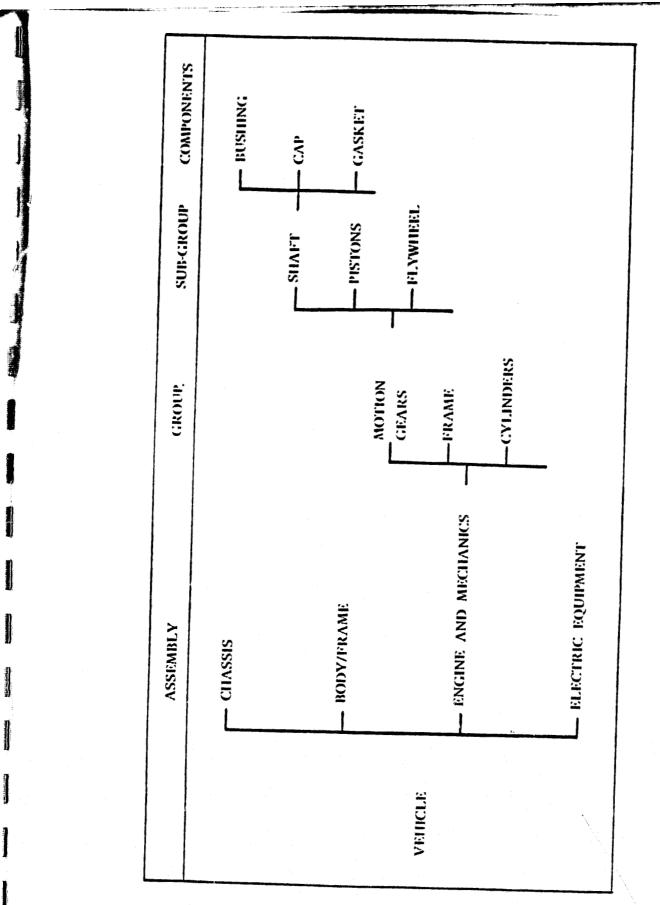
- Electrical equipment.

For each assembly the vehicle breakdown is further developed throughout the "GROUPS" and "SUBGROUPS" level down to the "COMPONENT" level as shown on Figure 4.3-4.1.

A.3-4.2 Component Cost Analysis

The manufacturing drawings of the various parts, components and subassemblies are analyzed to identify materials characteristics and quality, dimensions, tolerances etc.

The production cost of the UNFINISHED PARTS is first calculated in kL/kg (or \$/kg): the additional costs for FIRST PROCESSING and PARTS FINISHING are then added as appropriate together with the current cost of standard parts from EXTERNAL SUPPLIERS.







A.3-4.3 Labor Cost Analysis

The manufacturing drawings are then analyzed to identify the appropriate production cycles and define the cost effectiveness of production organization to optimize the mix of the following objectives:

Short manufacturing time

- Minimum manpower

- Simple production and tooling equipment

Based upon the existing production requirements a processing cycle is defined for the various components which includes a list of the machinery and tooling to be used. Processing cycle and assembling times, as well as machine set-up time where appropriate, are identified step by step, so that optimal work sequence and timing could be obtained.

Where small batch productions are appropriate an assessment of the incidence of machine set-up on the total process cycle is made to determine the optimal batch size.

A.3-4.4 Investments

On the basis of the expected cycle times upon evaluation of the effects of machine set-up, rejects, replacement and machinery efficiency, the actual machine load is evaluated for the various parts. As a result the amount of equipment necessary to achieve the required production level and the corresponding value of the investment for assembly lines, machinery, fixtures, gauges and tools can be defined.

The plant size, number of workers and plant related services can therefore be identified leading to the total investment value. The projected construction and tooling machinery cost must be continuously updated using the established relationships with the various contractors and suppliers.

A.3-4.5 Manufacturing Costs

The projected manufacturing times are converted into manufacturing costs according to the projected average hourly labor rates including both direct and overhead manhours. The expenses resulting from general and specific investments are expressed as appropriate in yearly depreciation costs taking into account expected interest rates.

The total production cost is obtained by adding the total cost of parts materials previously identified.

Based upon the number of vehicles to be produced on a yearly basis the total vehicle cost can be accordingly defined including an estimated additional cost to account for the improvements and design changes to be experienced during or after the first year of production.