clean air car race

A SUMMARY REPORT

clean air car race 1970

a summary report

Prepared by the
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This document was supported by contract #CPA-70-169 from the Environmental Protection Agency.

FEBRUARY 1971

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The symbol on the cover is the official CACR logo and is patterned after the international traffic sign meaning "do not."

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FOREWORD

H. G. Wells once said that future history will be a race between education and catastrophe. In 1969 a spirit of impending catastrophe was darkening the university horizon. Students were forcing the realization that more national attention must be given to social or human problems, and protesting appeared to be very effective in getting attention. Often times attention seemed to be the only reward which they received; however, more students wanted to become part of a constructive rather than a critical action.

In the Spring and Summer of 1969, I came to believe that the quickening desire on the part of more students to get involved in a relevant and constructive issue might lead to a favorable reception for a clean air car race. At the same time, the nation seemed to be struggling with the perplexing problem of whether our technical progress must inevitably be detrimental to our social goals. Many of us engineers believed we had simply given to society what it wanted, and if the consequences were not as welcome as the comforts and convenience then we would have to work together to determine new goals.

In retrospect, I believe that a great many people benefited from the race. It has left its certain mark on the history of the automobile, and it undoubtedly has influenced the lives of many student participants who were, or soon would be, at that crucial point of setting out on a career. It seems to be affecting the history of some universities, as I understand that several faculties from the competing universities are changing their plans to include much more student involvement in constructive and socially relevant programs.

I know also that the experience was of great value to each member of the Organization Committee. Upon taking over responsibility for the race in February 1970 they were a confident group but not always sure of their authority. It was quickly realized that they might be responsible for spending or controlling the allocation of over one hundred thousand dollars (it turned out to be a large fraction of a million dollars) and they wondered whose "approval" was necessary on some major decisions. However, as their own decisions established a base of confidence in their judgment they learned that authority comes from responsibility and that no "approvals" were necessary. In short, they now had an insiders view of "the establishment."

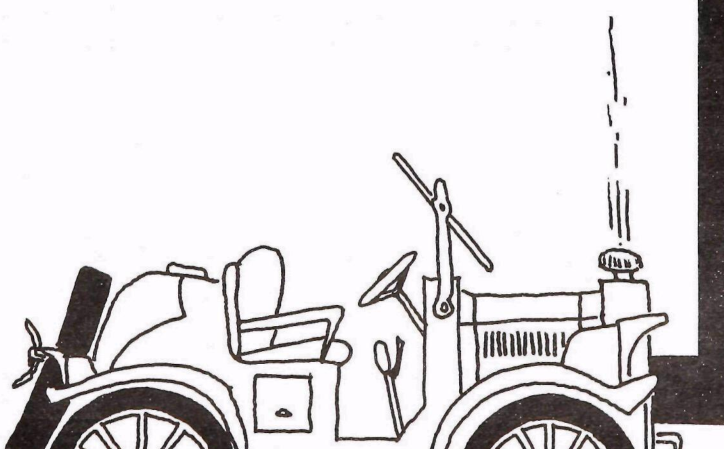
Lastly, I learned once again what intelligent young men and women can accomplish when they put their energies to a task which they believe is important. It there is a generation gap, I want to be counted on their side.

February 10, 1971

Dr. Milton U. Clauser

First faculty advisor to
the Clean Air Car Race
Organization Committee

I



I. THE AUTOMOBILE AND AIR POLLUTION

INTRODUCTION

Although the existence of the automobile on city streets dates back to the first years of this century, its role as a contributor to air contamination did not receive wide acceptance among scientists until within the last two decades. Factual evidence that urban area smog was chemically related to automobile emissions had been produced and acknowledged by scientific groups in the early 1950's. Despite vehement disagreement which ensued between government and the automotive industry on this volatile issue, research and development programs were initiated by both groups in an effort to identify the internal combustion engine's sources of pollution and determine what corrective action might be taken.

The roots of the general pollution problem, however, had already buried themselves deeply within the American value structure and, in retrospect, there should be little wonder that the related issue of automotive air pollution took so long to resolve. Traditionally, American society had not concerned itself with the economics of pollution of any type; a price tag had never been levied upon the consumer for the presence and continuing accumulation of unwanted and harmful materials in his natural environment. This century's value systems dictated that all decision making be oriented toward product development which took the most direct route, namely, minimizing cost and maximizing convenience and performance. Eventually, the alarming rates of urbanization and population increase compelled the U.S. to treat the issue of pollution by-product formation at all levels of decision-making. The rampant pace of technological development could no longer go unchecked in the expectation that our environment would naturally continue to absorb and adjust. Applying the brakes and opting for pollution control techniques, then, is perhaps just as much a societal problem as it is a question of coping with science and technology, provided one understands where the actual sources of inertia lie.

THE SOURCES OF AIR POLLUTION IN THE UNITED STATES

The recent recognition of pollution as a major national problem has spawned countless programs of investigation and research within government, industry, private foundations, and educational institutions. However, the data available to date is incomplete, estimates abound, conclusions are tentative, and disagreement inevitable.

The total air pollution emissions from all sources for the calendar year 1968 has been estimated at 214 million tons on the basis of a nationwide inventory conducted by the Federal government.[1] (See Fig. I-1)

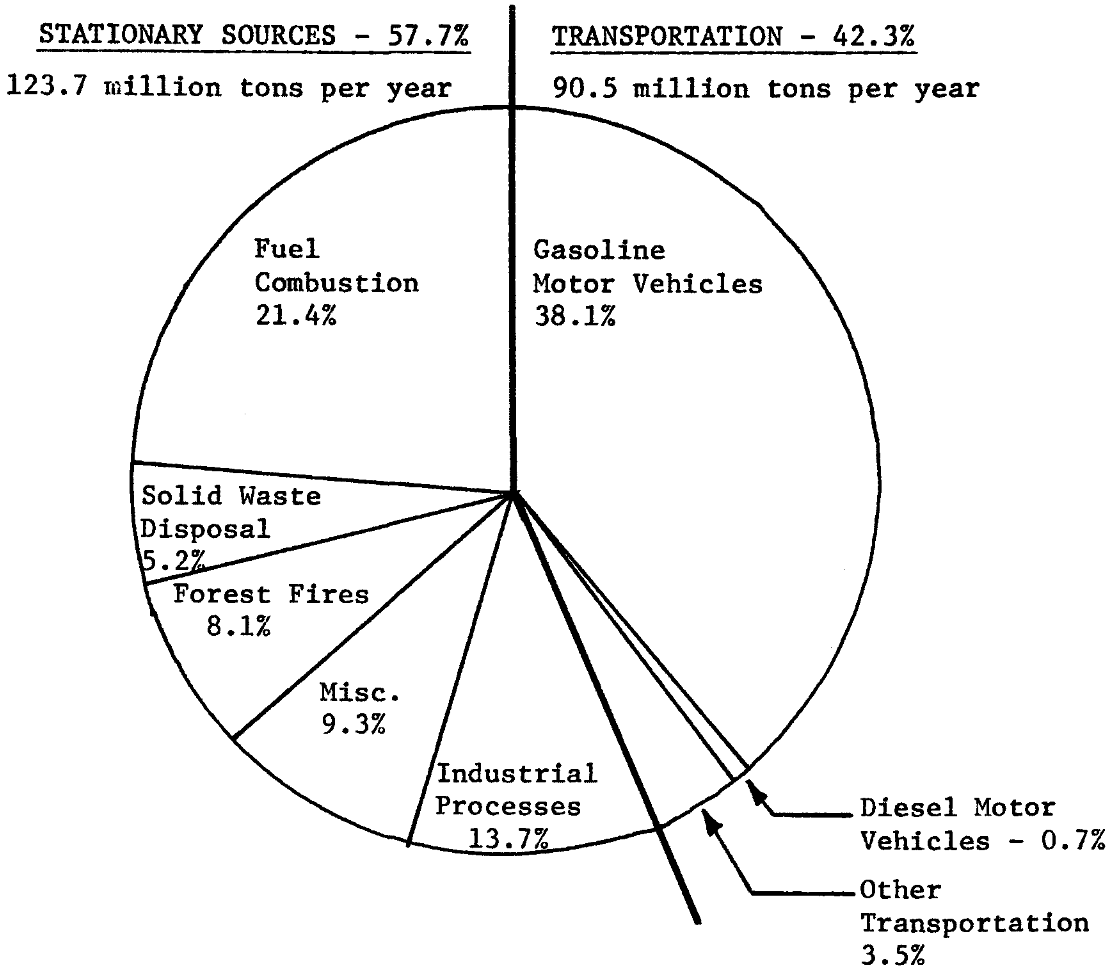


Fig. I - 1: U.S. air pollution emission levels by source for the calendar year 1968

Motor vehicles on the highway today account for roughly 40% by weight of all pollution being emitted into the nation's atmosphere each year. The principal contaminants for which it is responsible are carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x). Particulate matter emitted by the automobile, almost all of which is lead, and oxides of sulfur are practically negligible as far as the automobile's contribution to the total levels of these air contaminants is concerned. (See Fig. I - 2).

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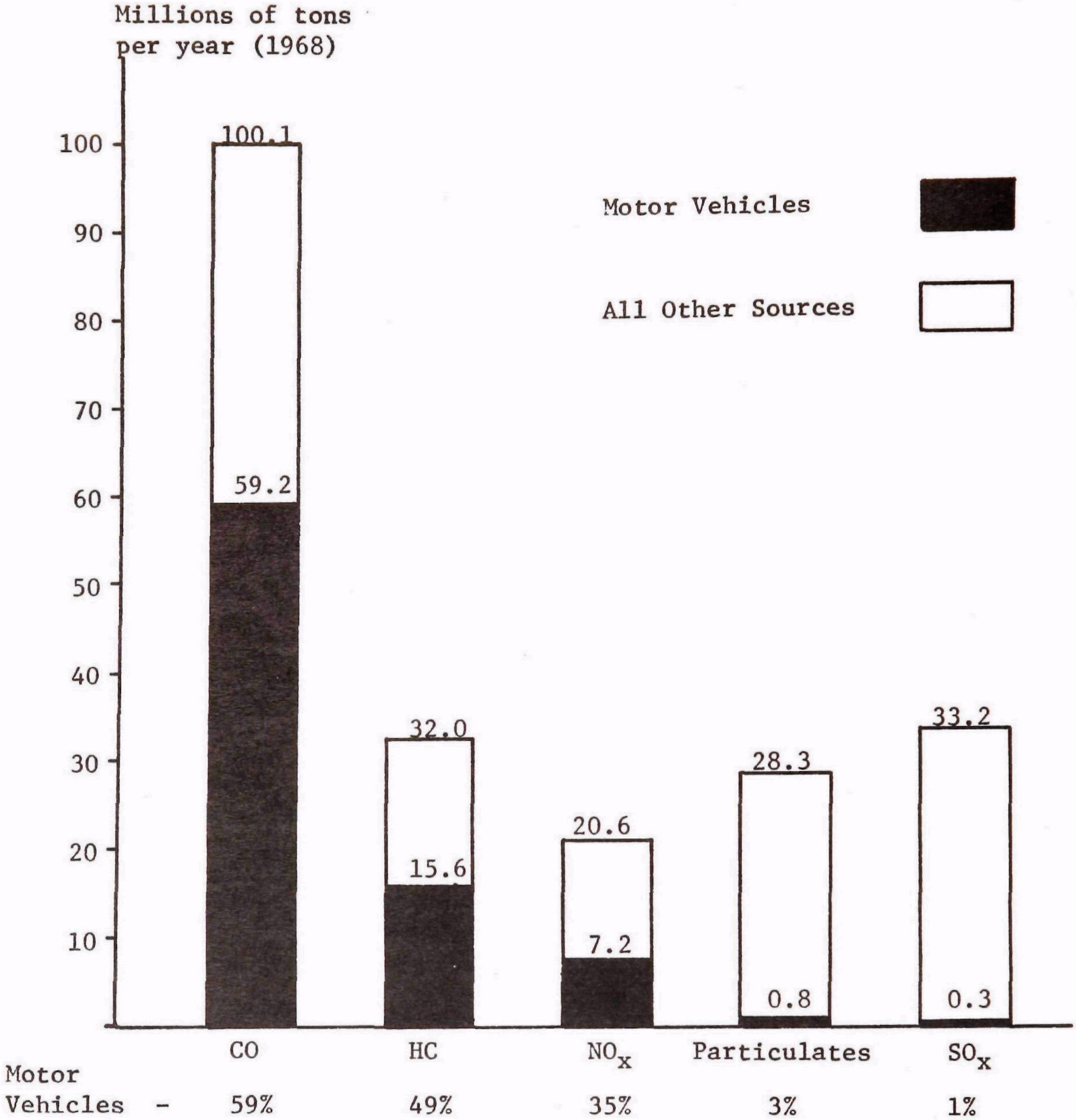
[1] U.S. Dept. of Health, Education, and Welfare, Nationwide Inventory of Air Pollution Emissions, 1968, U.S. Government Printing Office, August, 1970.



Source: U.S. Dept. of HEW, Nationwide Inventory of Air Pollution Emissions, 1968.

Fig. I-2: The motor vehicle's contribution to five major air contaminants.

Table I-1 provides a further breakdown of information on automotive emissions as regards the use of diesel fuel vs. gasoline in internal combustion engine (ICE) power plants.[1]

Table I-1

Automotive Pollutant Percentages vs. Type of Fuel Being Combusted.

PERCENT OF TOTAL AIR POLLUTION

	HC	CO	NO_x	Partic.	SO_x	Total
Gasoline	47.5%	59.0	32.0	1.8	0.6	38.1%
Diesel	1.3%	0.2	2.9	1.0	0.3	0.7%

When discussing atmospheric pollutants, the following facts are important to note:

1) The different pollutants, carbon monoxide, hydrocarbons, oxides of nitrogen and particulates each have different effects on human health and the environment. The total tonnage of pollutants emitted by the automobile does not measure its contribution to the air pollution problem, thus each pollutant must be considered separately.

2) Some of the products of fuel combustion, e.g. hydrocarbons and oxides of nitrogen, react with each other and other compounds in the atmosphere. Nitric oxide (NO), for example, is the oxide of nitrogen emitted during normal ICE operation which is oxidized in the atmosphere to nitrogen dioxide (NO_2). Together, NO and NO_2 are often referred to as the oxides of nitrogen (NO_x) when talking about automotive emissions. Another example is the complex interaction of hydrocarbons and NO_x in the presence of sunlight; the chain reaction which takes place results in the formation of photochemical smog, a major component of which are irritating oxidants. The Los Angeles basin is the worst example of this photochemical smog and offers ample evidence of its damaging effects.

3) Hydrocarbon emissions cover a range of many different organic compounds which vary in their basic molecular structure, formula, and associated chemical and physical properties. The composition of the hydrocarbon emissions depends on the composition of the fuel burned. Simpler fuels such as methane (CH_4) and propane (C_3H_8) result in hydrocarbon emissions that are less reactive in the photochemical smog process than hydrocarbon emissions from gasoline combustion.

HEALTH EFFECTS OF AIR POLLUTION

Hydrocarbons, carbon monoxide, oxides of nitrogen, and various photochemical oxidants are all toxic of themselves when found in sufficient quantity in the atmosphere. Current medical health effects result from variable dosages of each pollutant type and how serious the effects become with increasing time length of exposure.

The presence of NO_2 in sufficiently large quantities is a suspected cause of reduced visibility in urban atmospheres, and may inflict damage upon lung tissue. Both hydrocarbons and photochemical oxidants are suspected of being the responsible agents for eye and throat irritation and respiratory disease aggrevation.

It has been clinically shown that CO impairs the oxygen-carrying ability of the blood; small concentrations can reduce usual acuity and motor ability; large doses are fatal.

Particulate emissions from the automobile are the major source of lead in the environment. In general particulate matter in the atmosphere reduces the amount of solar energy reaching the earth and reduces visibility. It is a health hazard through its effect on the respiratory system, and a cause of a wide range of material damage.

A number of documents published over the last three years by the Air Pollution Control Office (APCO) in the Environmental Protection Agency (formerly the National Air Pollution Control Administration in the Department of Health, Education, and Welfare) contain extensive reporting on the different types of pollutants found in the atmosphere, how to measure their concentration, and what effects might be attributable to each. These documents are commonly referred to as the Air Quality Criteria. The CACR Committee recommends that anyone interested in pursuing the effects of the different air pollutants in more detail consult these documents. The titles and dates of publication have been listed below; copies may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

Air Quality Criteria for Particulate Matter, Pub. No. AP-49, January 1969.
Air Quality Criteria for Sulphur Oxides, Pub. No. AP-50, January 1969.
Air Quality Criteria for Carbon Monoxide, Pub. No. AP-62, March 1970.
Air Quality Criteria for Photochemical Oxidents, Pub. No. AP-63, March 1970.
Air Quality Criteria for Hydrocarbons, Pub. No. AP-64, March 1970.
Air Quality Criteria for Nitrogen Oxides, Pub. No. AP-84, January 1971.

AUTOMOTIVE SOURCES OF POLLUTION

In the environment, natural levels exist for the different atmospheric elements and compounds. Urbanization and industrialization have increased the former ambient levels (or geophysical component) substantially. Of notable interest are the high concentrations of pollutants emitted by the automobile in regions of high traffic density. Figure I-3 shows schemetically, for example, the concentration of CO in the vicinity of our nations roadways. In busy city centers, CO levels are now sufficiently high to constitute a health hazard. Corrective action to protect the public's health, and such action is now underway.

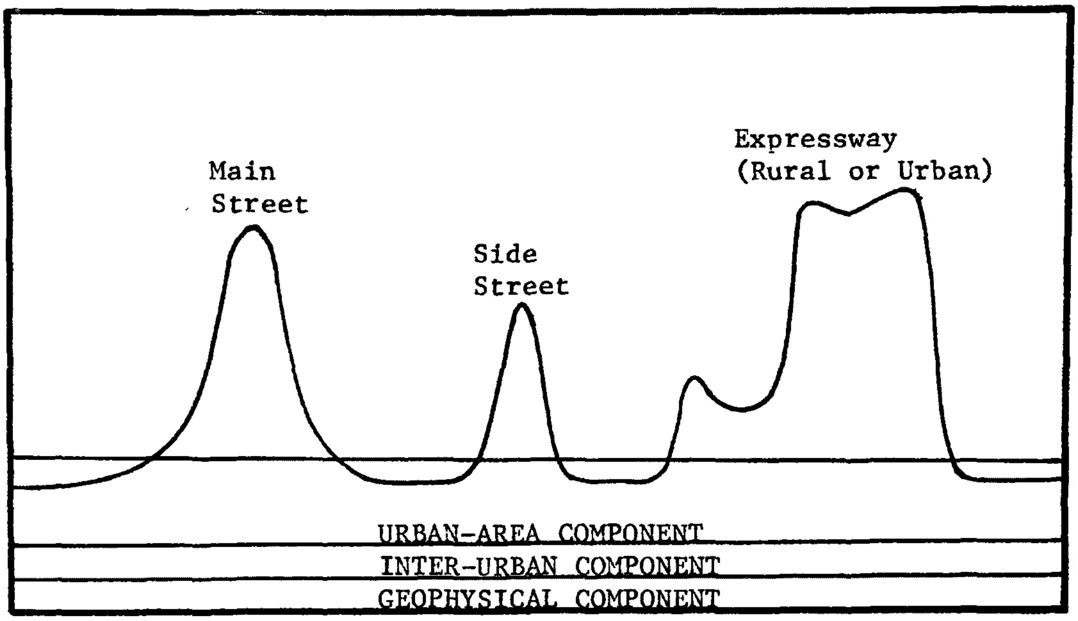


Fig. I - 3: Hypothetical profile of CO concentrations in the environment.

The uncontrolled automotive spark-ignition engine had three major sources of air pollutants: crankcase blowby, fuel evaporation from the fuel tank and carburetor, and exhaust emissions. Crankcase blowby has been controlled since about 1964, nationwide, by returning the blowby gases to the air intake through a positive crankcase ventilation (PCV) value. Evaporative losses have been controlled on 1970 and subsequent model years by employing vapor-tight systems on fuel tank and carburetor. Exhaust emission control, however, has been and is the most difficult of the tasks confronting the automotive engineer as the the three pollutants CO, HC and NO_x have different origins inside the engine cylinder and require different control techniques and devices.

Vehicle exhaust customarily contains about 60% of the total HC emissions and 100% of the CO, NO_x, and particulate emissions for a completely uncontrolled automobile. Efforts by the automotive industry over the past five years have succeeded in reducing the magnitude of hydrocarbons by 70% and that of CO by 60% for 1970 model year vehicles. The recently passed Amendment to the Clean Air Act (December, 1970) requires that a virtually pollution-free automobile be manufactured by the industry in the 1975-1976 model year with all pollutants having been reduced by 90 to 97% over uncontrolled vehicles.

Figure I-4 illustrates what effect the exhaust emission control procedures could have on the total emissions of HC, CO, and NO_x into the atmosphere if the Federal standards are attained. Note that the absolute levels begin an upward trend around the 1980 model year because while most vehicles on the road will posses the proper emission control devices, the number of total vehicle miles per year will once again have become the dominant factor in this calculation.

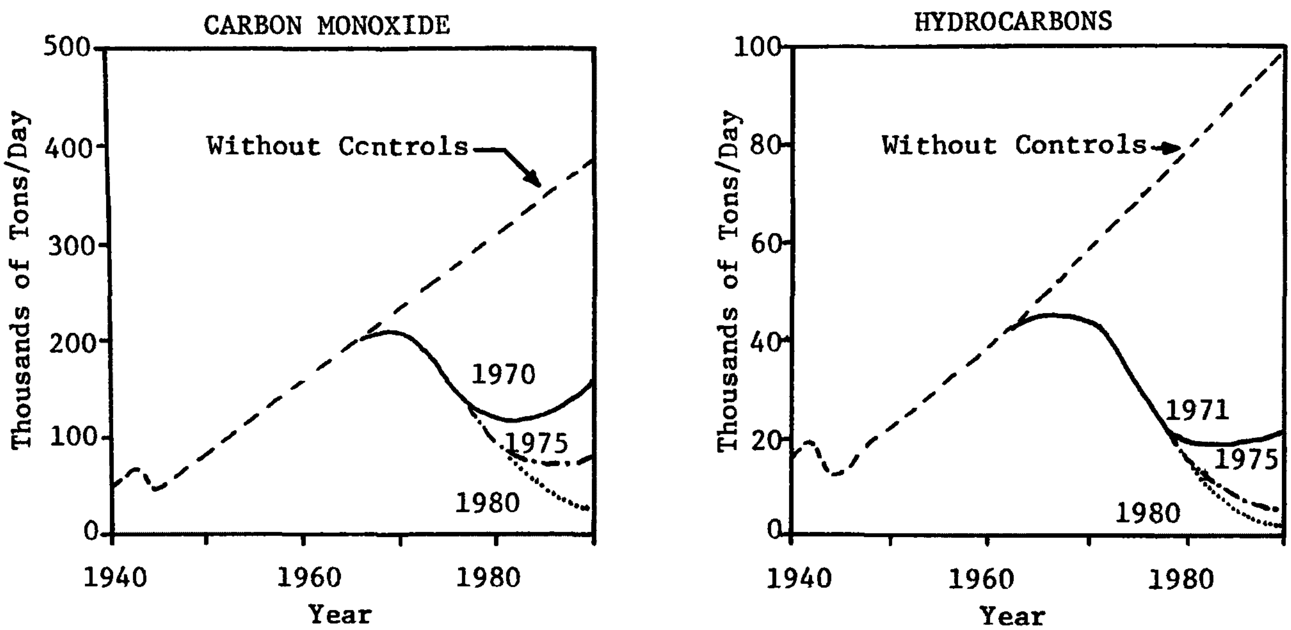


Fig. I - 4: Current automobile pollutant emission levels and projected estimates on a national scale.

CURRENT PROCEDURES FOR CONTROLLING THE EXHAUST EMISSIONS FROM INTERNAL COMBUSTION ENGINES[2]

This is more or less where the Clean Air Car Race (CACR) came into the picture. The hope of involving university groups in the automobile pollution control effort could not have received a better shot in the arm than the discovery that both the Federal government and the automotive industry would be willing to sanction such involvement. The original concept was to have a competition in designing and building automotive power plants, be they ICE or unconventional, that could attain the then-proposed 1975 Federal standards for exhaust emission control. This, in a nutshell, was the intent of the event. Since the focus of this chapter has been on the conventional automobile, the conluding paragraphs review the techniques employed by those CACR entrant teams who went the ICE route.

Several methods are being considered to reduce emissions from internal combustion engines. Since they will be referred to repeatedly in the technical reports on the CACR vehicles (see Appendix B), their descriptions and the principles upon which they operate will be summarized here. Due to the trade-offs which often exist in the formation of nitrogen oxides, carbon monoxide, and hydrocarbons during combustion, the set of techniques which any entrant picked represented his assessment of the optimum resolution of those trade-offs. (See Figure I - 5).

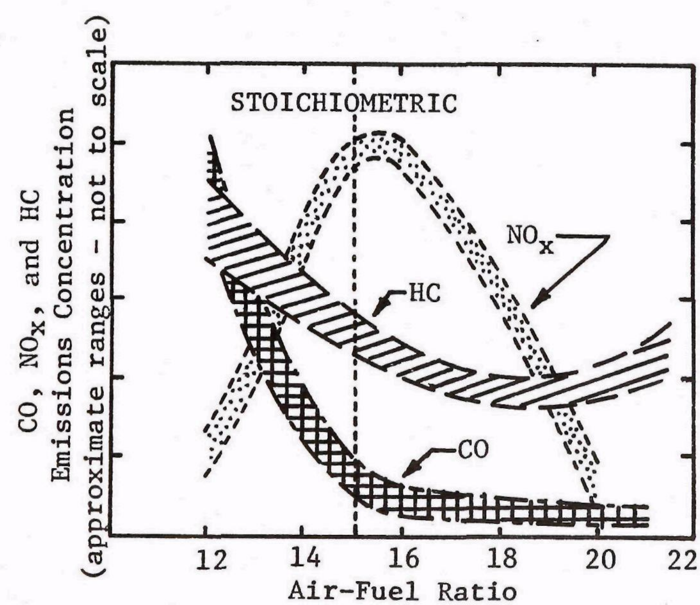


Fig. I - 5: Trade-off curves illustrating the formation of HC, CO and NO_x within the combustion cylinder as a function of air-fuel ratio.

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2. U.S. Dept. of HEW, Control Techniques for Carbon Monoxide, Nitrogen Oxide, and Hydrocarbon Emissions from Mobile Sources, U.S. GPO, March 1970.

Hydrocarbons can be reduced by increasing the air-to-fuel ratio (running lean), by creating a higher exhaust gas temperature, or by lowering the "quench mass" within the combustion cylinder. Running lean simply provides a greater ratio of oxygen in the cylinder with which the reduced amount of fuel can react. By running richer than the well-known stoichiometric condition of 14.5 to 1.0, i.e., what is chemically ideal, hydrocarbons are virtually forced to skyrocket. Raising the exhaust gas temperature increases the reaction rate between the hydrocarbons and oxygen in the exhaust stream.

An extension of the concept of lean operation and higher exhaust temperatures for hydrocarbon reduction is the exhaust reactor, of which there are two major varieties - thermal and catalytic. A thermal reactor consists of an insulated chamber which provides the necessary residence time at high temperatures (around 1500°F) for the hydrocarbons within the exhaust gases to react. Frequently air is injected upstream of the reactor to increase the O_2 content of the exhaust gas. A catalytic reactor operates similarly to the thermal reactor, but includes the addition of some surface catalyst (such as platinum) on an inert substrate which enables it to function at lower temperatures and higher efficiency. Air injection is often used with catalytic reactors as well.

In a thin zone along the metal surface of the combustion chamber, temperatures are not high enough to allow combustion. The quenching phenomenon which results is a major source of hydrocarbons. Decreasing the quenching surface area by either using a smaller engine, having fewer cylinders for a given engine displacement, or optimizing the bore-to-stroke ratio can reduce hydrocarbon emissions. Greater turbulence within the cylinder during the injection of the air-fuel mixture or a higher compression ratio can decrease the quench zone thickness.

Carbon monoxide is produced in much the same way as the hydrocarbons, although air-fuel ratio becomes a more important factor and quenching less important. Catalytic and thermal reactors are both effective in the control of CO as well as hydrocarbons.

At the high temperatures which momentarily exist within the cylinder during flame propagation (above 4000°F), a small fraction (0.3%) of the nitrogen in the air-fuel charge is oxidized to nitric oxide NO. The process is highly temperature dependent, and is most easily attacked by utilizing various means to lower the peak combustion temperatures.

Lowering compression ratio and retarding the spark timing both reduce the rate at which nitric oxide is formed. Both these changes reduce the peak pressure within the engine cylinder and therefore peak temperatures are lowered. Running lean also results in lower combustion temperatures; but at an air-fuel ratio setting which is only slightly leaner than stoichiometric, it becomes counter-productive (see Figure I - 5), with the increased O_2 and N_2 supply counteracting the effect of reduced temperature.

With the addition of an inert substance to the air-fuel mixture, some of the thermal energy must be used to raise the temperature of the substance during combustion. Commonly, the inert substance used is 10%

to 20% of the engine exhaust itself, and less commonly, water is used. The former approach is called exhaust gas recirculation or EGR and the latter is referred to as water injection.

Finally, catalytic reactors can be used to reduce NO concentrations in the exhaust via the following reaction:

$$2NO + 2CO = N_2 + 2CO_2.$$

This requires low levels of oxygen in the exhaust to avoid competition between O_2 and NO for the available CO. Consequently, the same reactor cannot be used to reduce both hydrocarbons and NO.

Please realize that the above-listed procedures constitute only a few of the techniques which can be employed in controlling HC, CO, and NO_2 output from automobiles.

II

II. THE 1970 CLEAN AIR CAR RACE:
A SYNOPSIS OF EVENTS
A SUMMARY OF ACHIEVEMENTS AND RELATED IMPACTS

NOTA BENE

In the 1970 Clean Air Car Race (CACR), seven vehicles out of 43 demonstrated particular low pollution potential by exceeding stringent exhaust emission control standards which had been established by the organization committee. However, because the CACR test procedure for measuring the exhaust gas pollutants did not correspond on a number of points to what had been specified in Volume 33 of the Federal Register (see Section A of Chapter V), there is some question as to whether these same vehicles have actually bettered the proposed Federal standards for exhaust emission control, namely:

	Proposed Federal Standards at Race Time (August 1970)	Federal Standards, 1970 Clean Air Act Amendments	
	1975	1975	1976
Hydrocarbons (HC):	0.5 gm/mile	0.45	0.45
Carbon monoxide (CO):	11.0 "	4.7	4.7
Nitrogen oxides (NO_x):	0.9 "	3.0*	0.4*

*Not yet officially announced by the Federal Government. Proposed Standard for 1973.

Although seven of the CACR entrant teams had reduced the pollutant levels in their vehicle exhausts below the then-proposed 1975 standards, the differences between the CACR and Federal test procedures should make one sufficiently cautious before concluding that the breakthrough to the automotive air pollution problem has been found. (See Chapter V for an explanation of the CACR exhaust emissions test procedure.)

IN RETROSPECT

Several tangible objectives had been drawn up by the CACR organization committee during the spring of 1970 while preparing for the competition. The objectives as formulated by the committee at that time have been reproduced below:

1. To involve educational institutions in the field of automotive technology and control of pollution emissions in vehicle exhaust;

2. To stimulate interaction in this field between educational institutions and industries with ongoing programs;

3. To assess the state-of-the-art in this field with respect to both potential short and long range solutions; and

4. To encourage the design and development of unconventional (non-ICE) power plants for vehicular propulsion.

In the committee's opinion, a fair statement to make in retrospect is that the initial goals were in part eventually realized. The reader is invited to conclude for himself what the CACR actually proved and whether the participants, including academia, government, and industry, realized any gains from becoming involved in a project of this nature.

The 1970 Clean Air Car Race witnessed 43 student teams from 32 different educational institutions successfully complete construction on various types of vehicle power plants which were subsequently tested for exhaust emissions, general performance, fuel consumption, and reliability. A number of teams had received strong industrial support consisting of funds and technical assistance, while other student groups had relied upon textbook knowledge and plausible experimental methods. Both those who made the starting line on time and the teams which never completed vehicle construction discovered that the reduction of exhaust emissions for any type of automotive power plant is not a matter to be taken for granted. The technology whereby exhaust emissions can be reduced, the cost involved, and the task of educating the consumer to accept his share of the responsibility—these issues were dealt with firsthand by the CACR student-faculty teams. With the conclusion of the CACR, the participating academic groups had learned a great deal about existing and potential control methods for ICE exhaust emissions, the use and availability of different types of automotive fuels, and the challenge of promising alternative propulsion systems.

A SYNOPSIS OF EVENTS

The history of organization committee activity is a complete story in itself (see Appendix C), but tells only half of what actually happened during the 1970 Clean Air Car Race. Every participating group created its own sphere of influence and undoubtedly experienced a number of successes and failures therein. Crossroads confronting the young engineers included correctly analyzing combustion chamber chemistry, making design decisions regarding a total emissions control package, and securing the essential support from university administrations and interested industrial firms.

With many forces interacting on the controversial subject of automotive air pollution, the CACR provoked quite a stir in government and industrial circles as it set out to demonstrate that the then-proposed 1975 Federal standards could be attained now.

To meet the CACR entrance requirements, the major obstacle confronting a potential participant was the reduction of vehicle power plant emissions to the 1975 standard levels on the basis of a hot start, California seven-mode cycle test. Other qualification requirements included that the vehicle be four-wheeled and fully enclosed, have a two-passenger minimum capacity, and be capable of traveling 60 miles in 90 minutes without refueling. The test vehicles also had to comply with the 1970 Federal safety standards to insure legal passage on the interstate highway system.

Competition rules were drawn up by the organization committee and 93 student-faculty teams at approximately 60 colleges and high schools completed preliminary registration. The event had been divided into three major time blocks, namely: pre-race testing at MIT in Cambridge, cross-country travel, and post-race testing at Caltech. There would be a winner for each class of power plant type determined on the basis of scoring formulae devised by the organization committee. An impartial panel of experts on automotive air pollution had agreed to select an overall winner, using subjective criteria such as design cost-effectiveness, practicality of the concept, and potential for public acceptance.

The period of competition took place between August 17th and September 2nd. The vehicles were tested on three separate occasions for exhaust emissions, while roadway performance and noise emission were assessed only once, prior to the start of cross-country travel. While journeying between Cambridge and Pasadena, fuel economy was measured for each entrant vehicle over a limited portion of the route and an accurate record of malfunctions was maintained to establish a measurement of each vehicle's reliability. Upon arrival in Pasadena, the third of the exhaust emission tests was administered and a final score for each team was immediately computed by the organization committee. The winners were announced at an awards banquet held on the evening of September 2nd, the official conclusion of CACR activity.

After the event, the organization committee returned to MIT, where its post-race responsibilities were essentially to disseminate the CACR results to interested groups as well as to the general public. During this time, films on the CACR have been produced, this summary report has been published, and over 50 presentations by organization committee members have been made upon request by interested schools and civic groups.

A SUMMARY OF ACHIEVEMENTS AND IMPACTS

The 1970 Clean Air Car Race succeeded in generating widespread interest at different levels within a number of organizations, the most notable of which were the engineering departments of universities, the automotive industry, and the National Air Pollution Control Administration (NAPCA) within the Department of Health, Education, and Welfare.[1] The CACR story concerns to a significant degree the group interaction between these different organizations and the sense of accomplishment or failure felt by each after the awards had been presented in Pasadena.

This chapter is devoted to assessing the achievements and impacts for which the CACR was responsible. Many comments, opinions, and criticisms have been collected since the race's conclusion toward this final, overall assessment. Much of what follows embodies the common feelings of those who participated in the CACR. Some of the issues, however, remain extremely controversial and will go without resolution.

There are five major areas, outlined below, in which the CACR produced meaningful impact:

1. Engineering education within universities,
2. Technical achievements: system design and hardware development,
3. Interaction between participating organizations,
4. Political impact, and
5. Public information.

Engineering Education

The control of exhaust emissions from the conventional internal combustion engine or the development of an alternate type of automotive power plant presented a formidable project for any interested and willing student-faculty team. Impressed with the importance of the task, however, at least 93 groups initiated efforts to grapple with the automotive air pollution problem. High motivation was stimulated by the personal satisfaction of becoming involved in an existing problem area of immense concern to the general public. The need to concentrate interest and allow for creative ability in student engineering projects was apparently satisfied by an undertaking of this nature, according to most CACR participants.

Because university groups hunger for meaningful project-oriented experiences, the 1970 CACR received instant acclaim as a rather effective

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[1]In December of 1970, NAPCA was transferred to the newly formed Environmental Protection Agency (EPA) and has since changed its name to the Air Pollution Control Office (APCO).

means for involving students in the issue of automotive air pollution. With very little time to prepare, entrants found themselves on an extremely steep part of the learning curve. During the competition, the CACR created a natural arena for a meaningful exchange of ideas, as was evidenced by discussion at the technical report presentations and informal bull sessions during pre- and post-race activity. In retrospect, the competitive nature of the event was an equally important factor, in that the desire to participate and the necessity of brain-storming for answers to the problem were significantly enhanced.

The cooperative effort required of these student-faculty teams compelled them to divide the labor efficiently in order to cope with the extremely short timetable for preparing the vehicle. Researching available literature on the chemistry of combustion for the respective power plant types, understanding the test procedures used to measure a vehicle's exhaust emissions, and investigating existing technological solutions--all this had to be done with very little time to spare. Consequently, it was little wonder to observe the spirit of cooperation exhibited by most teams during the high-stress conditions which accompanied the competition, for similar conditions had prevailed all during their preparation for the CACR.

The practical experience received in an event of this type is perhaps the most valuable asset which students and faculty alike carried back to their respective academic institutions. There is no doubt that everyone involved learned a good deal about the problem of controlling exhaust emissions for any type of automotive engine. An encouraging sign in the race aftermath and the 1970 Clean Air Act Amendments is the sustained effort being put forth by many of the teams to perfect their ideas.

The importance of a continuing commitment cannot be overemphasized if the universities are ever to help solve a problem which their own inactivity has helped to create.

Technical Achievements

All developments taken into account, no major breakthrough in the field of vehicular exhaust emission control resulted from the CACR effort. Nonetheless, innovation as well as harnessing of existing ideas highlighted the student-faculty projects which attempted to demonstrate the potential capability of attaining low pollution emission levels.

The reader is encouraged to review the technical report digest presented in Appendix B, which outlines the various modifications made to the present internal combustion engine (ICE) and describes the unconventional approaches taken in developing some of the advanced power systems. For most teams, total system design and development proved to be too great a task, requiring more time than was practically available. Consequently, a concentration on component technology characterized the main thrust of effort.

The teams which by definition engineered an entire propulsion system consisted of the non-ICE entries. Of noteworthy mention are the following:

1. The MIT gas turbine, with its experimental control system package and electric transmission drive.

2. The U. of Toronto hybrid-electric, which possessed four distinct modes of engine operation due to parallel arrangement of the electrical and mechanical drive systems.

3. The electric vehicles from Cornell U. and Stevens Institute of Technology, which, while displaying no advancement in battery technology, demonstrated reasonably reliable roadway performance during continuous operation.

Within the ICE category, the Wayne State entry had combined many conventional techniques for controlling exhaust emissions with a number of innovations based upon research work which had investigated the importance of various combustion parameters. Careful control of the air-fuel ratio, the use of exhaust gas recirculation, and the installation of catalytic reactors were the major steps taken by most teams in reducing the exhaust gas emissions. Reducing valve overlap and employing a submerged electric fuel pump in the gas tank were two examples of the engineering innovation used by Wayne State to obtain even lower pollutant levels.

The gaseous fuel vehicles, namely those running on liquid propane and liquid or compressed methane (LPG, LNG, and CNG respectively), demonstrated by far and away the greatest consistency in maintaining low exhaust emission output.

In the liquid fuel's catagory, emissions were usually higher because the control problem is more difficult. Poor fuel vaporization with a cold engine results in significantly increased emissions during engine warm up. The Stanford entry with alcohol as fuel achieved the lowest emissions. The UCLA entry showed that the diesel cycle even without exhaust emission controls, has the potential of being a low emission, highly reliable, and economically practical system.

Other teams experimented with fuel injection, dual fuel operation, and the design of thermal and catalytic reactors. The approaches taken are too numerous to list here, but have been briefly outlined at the end of Chapter I and covered in detail in the entrant team technical reports.

Interaction

The long list of acknowledgements at the end of this document readily indicates how essential it was to have the backing of several organizations within both government and industry in making the CACR an event of widespread national interest. The automotive industry provided much of the necessary equipment and manpower to conduct the vehicle testing that had been planned for the competition. Entrant teams secured funding, technical assistance, hardware, and the use of testing facilities from both local and nationwide industrial concerns to defray a large part of their project costs. The Federal government assisted the organization committee in a number of areas, the most important of which was the coordination of the noise and exhaust emissions testing. The technical expertise and support capability, which in most cases only government and industry could provide the ambitious student-faculty teams, was in high demand and, in fact, indispensable to the CACR.

Establishing guidelines for the CACR competition also provoked a sizeable amount of interaction between test engineers from NAPCA and the automotive industry. Agreements concerning the type of emissions testing, availability of equipment, and time constraints had to be reached after only a few meetings and many long phone calls. The controversial question of having vehicle test results compared against Federal standards which did not correlate with the measurement procedure used was discussed at length and the obvious pitfall seemed inevitable. But despite the pressure of having too much to resolve in too short a time span, the importance of maintaining the forward momentum was realized and preserved by mutual agreements and compromise.

The interaction between academic groups, government, and industry resulting from the CACR took place at practically every decision-making level within these respective organizations. Aside from university sponsorship, a fantastic amount of support was invested by NAPCA, the automotive industry, and the electric utilities. In each case, the student representatives of entrant teams or the organization committee initiated proposals requesting assistance and pursued the matter by working closely with an official from the industrial concern or governmental agency. Test engineers from these organizations were also consulted frequently, and exposure to in-house projects during laboratory tours revealed to the student and faculty visitors how professional groups were approaching the problem. The discussion and exchange of ideas taking place on such occasions was an encouraging sign of the interest of the engineering students in what could be done. Hopefully, the students' experience in the CACR, although brief in duration and inconclusive in many of its test results, gave the student community a feeling for a problem where academic knowledge is indeed relevant, and will motivate continued involvement in this field.

If the automotive industry can detect a continuing commitment among university groups to help work toward a viable solution, then the investment has most certainly been a worthwhile one. In any case, many student groups now have an increased appreciation for the difficulty of the task confronting the automotive industry since passage of the 1970 Clean Air Act

Amendments. Pertinent questions such as economic feasibility and public acceptance of an emission-free vehicle were not tackled head-on in the CACR, and the fact that they have not been answered is a disturbing thought to those who must carry the work forward.

Political Impact

The Clean Air Car Race could not have been staged at a more appropriate time than the summer of 1970, when the issue of automotive pollution was prominent in the mind of every environmentally-conscious individual. Congress had just finished drafting legislation which accelerated the timetable for attaining already stringent exhaust emission control standards. Because certain vehicle entries in the CACR had performed extremely well during the emissions testing, congressional advocates of cleaner air were quick to seize on the test results and interpret them as factual proof of an existing solution. Although this was an obvious misuse of the data, the low pollution potential of these vehicles was not ignored by industry.

The stricter automobile emission standards contained in the recently passed 1970 Clean Air Act Amendments have definitely increased the workload ahead for the automotive industry (see Section B of Chapter V). The degree to which the Clean Air Car Race was instrumental in the passage of this legislation cannot be determined, but the test results certainly were reviewed by automotive experts within government and industry. The CACR fostered speculation that a solution in the near future was possible, and may have given a major boost to the impetus for political action.

Public Information and Education

A continuous public relations program was conducted by the organization committee prior to and during the CACR competition. It consisted primarily of press releases and was expanded to include taped interviews and television appearances during the race week itself.

The general information which the public has retained concerning the event probably boils down to a knowledge of there having been a student event which addressed itself to the environmental issue of automotive air pollution. The modifications actually made to the ICE and the development of other power plant types are of little interest to the public, although the questions of how much it all will cost and what the visible effects to the air will be are of primary importance. Thus, the CACR may have simply been viewed as an interesting demonstration of student concern, but one having little impact upon emissions-control decisions faced by the automotive industry.

A major failure of the CACR was the absence of an adequate public relations effort at the termination of the competition in Pasadena. Many people who had followed the event cross-country suddenly discovered that no information could be obtained on the race winners. Despite the preparation of a detailed press release containing the results of the competition, the delay in dispatching this release was an error that cost the committee the interest of the media.

When the committee first came into existence, extensive thought should have been given to a concerted public relations program with clearly formulated objectives. The question of what the public should learn as a result of this nationwide event was never really considered. In retrospect, public education could have been accomplished through the CACR, but it would have required more time, funds, and foresight.

The completion of two major film productions and this document are the fruits of committee effort since the finish of the race in September, 1970. One of the films is a documentary and has been tailored for general audience viewing, while the other is more educational in its content and is aimed toward a narrower audience. The committee has made a considerable effort in attempting to interest the three major commerical networks as well as the educational networks in televising both, either, or a combination of the films within the coming months. In addition, both films will be available for showing to schools and interested groups as soon as a sufficient number of copies are available.

Finally, over the past four months committee members have given well over fifty presentations to different universities, alumni clubs, civic organizations, and professional societies concerning CACR activity and the automotive air pollution problem. The presentation varies according to the audience and usually consists of a slide show documentary, a short lecture with summary comments, and, most recently, one of the CACR films. Interested parties should contact the committee at M.I.T. to make the necessary arrangements should a program of this sort be requested.

THE FUTURE

Although activity related to the 1970 CACR has essentially terminated, the committee has instituted a proposal to conduct an inter-university urban car competition in the summer of 1972. A pilot committee of five students has already been selected to head up organizational activity for this event. Judging from post-race inquires concerning another event of this nature, it is to be expected that this competition will attract a much larger entrant field. It remains a possibility that many international entrants will appear representing universities from countries other than Canada.

It is hoped that the new committee will benefit from the lessons of the CACR committee, and that the lead time of a year and a half will permit more attention to details than was apparent during the summer of 1970. It is the intention of the new committee to publish a set of rules. schedule of activities, and a guideline to policy before May 1, 1971. Noticification of the pending competition will be forwarded to interested parties and all accredited institutions prior to that date.

Finally, in a parallel effort by certain CACR committee members, several interested universities were approached on the idea of forming a non-profit corporation. Membership in the corporation would be confined to universities and colleges and each member would be represented by a Dean's level administrator from that particular institution. The expressed purpose of the corporation would be to sanction and actively support in a variety of ways, including financial, acceptable student organized intercollegiate competitions in the areas of science and engineering. While the formal planning stage in still being investigated, the proposal has been met by sound and dedicated support by those deans already approached. Indeed, the future of this organization is bright.

III

III. THE WINNERS OF THE CLEAN AIR CAR RACE

PROLOGUE

"We're not in this race as such to beat anybody; we're in this race to make a point of being involved in pollution control and making the general public aware of the general problems of pollution. And I think that these are the two principally most important goals. As far as I'm concerned, everybody that enters this race is a winner."

Doug Venn
U. of Toronto team captain
August, 1970

Although some teams displayed a greater sense of competitiveness than the Canadians from Toronto, the general point about "being involved in pollution control" speaks well for the CACR participants. Students in search of relevance had at last come to grips with a pressing problem in proportion to all of society - an extremely thorny issue over which government and industry had debated for the past decade with significant disagreement. The desire to help contribute to the solution of this existing problem was a strong motivating force behind the widespread involvement of educational institutions. In essence, the commitment put forth by students and faculty alike, despite what may or may not have been accomplished technically, did in fact make the whole event seem as if everyone that entered had been a winner. The preceding chapter which summarizes the acheivements of the CACR and points out the related impacts should be sufficient testimony to Doug Venn's statement.

CLASSIFICATION OF ENTRANT VEHICLE POWER PLANTS

Prior to pre-race activity at M.I.T. (see Appendix C), each vehicle participating in the CACR was placed in one of five separate classes for competition purposes. The division was based upon power plant type and has been reproduced below as it was originally defined in the CACR rulebook:

Class I: Internal Combustion Engine (ICE)

Class II: Rankine Cycle
External combustion with heat transfer taking place to the working fluid; examples include steam

piston, steam turbine, and Stirling cycle engines.

Class III: Brayton Cycle
Gas turbine which includes a variety of possible working fluids.

Class IV: Electric
A battery is the primary energy source; recharging occurs through off-board facilities such as charging stations.

Class V: Hybrid-electric
A battery is coupled to a separate on-board energy source (such as a piston engine) which accomplishes the recharging function.

During pre-race activity at M.I.T., the point was raised after the August 18th captains' meeting that a subdivision within the ICE class based upon fuel type being combusted in the vehicle power plant would be plausible. Consequently, those teams burning gaseous fuels such as liquefied natural gas (LNG), compressed natural gas (CNG), and liquid petroleum gas (LPG) were placed into one ICE subclass, while the engines running on liquid fuels such as gasoline, diesel fuel, and methanol constituted the complement. The chemistry of the combustion process for liquid vs. gaseous fuels was used to justify this major separation of competing groups and was readily accepted by all CACR participants. Moreover, the ICEs, containing 32 of the 43 CACR test vehicles, managed to alleviate the tension build-up somewhat by reducing the total number of teams vying for top honors within that class.

THE SELECTION PROCEDURE FOR THE CACR WINNERS

The selection of class and overall winners has been briefly mentioned in organization committee history which appears in Appendix C. A concise review of the actual selection procedure is one of the major purposes of this chapter and will assist the reader in understanding how the competition winners were determined.

Distinctly separate processes were employed by the committee to establish the class winners as opposed to the overall winner. Measurements of vehicle performance and emission characteristics were used to generate scores for each team by using mathematical formulae derived and published prior to the race; in this fashion, a winner for each power plant class was selected. The overall winner, on the other hand, required the decision of an independent panel of judges, which had been arranged for by the organization committee prior to the competition.

Scoring for the various class competitors was established by the committee according to the following formula:

$$S = E\ (P + R + FE)$$

where
S = total score
E = emissions factor
P = performance score
R = race score
FE = fuel economy score

Obvious emphasis has been placed upon the emissions score as can be seen from its importance in the above formula.

The derivation of the E factor and its possible range of values has been explained in detail in Section C of Chapter V.

The performance factor in the overall score was determined using a formula which has been explained in detail in Chapter IV. Measurements of vehicle acceleration, braking, general maneuverability, and noise emission comprised the test data used to compute vehicle performance scores. Each of the four tests had maximum possible value of 250; thus, P was always set at 1,000 points for any entrant team.

The race score, R, consisted of seven separate scores obtained on each of the seven different cross-country legs. The equation for determining R was as follows:

$$R = L1 + L2 + L3 + L4 + L5 + L6 + L7.$$

where
R = race score
L1,.....,L7 = leg scores

The maximum possible value for any leg score was established according to the distance constituted by that leg as a percentage of the total 3600 mile route. The maximum possible score for R was set at 1,000 points.

The fuel economy factor consisted of a calculation which determined the miles per million Btu of fuel obtained by each test vehicle during legs 3 and 4 (1,071 miles) of cross-country travel. The maximum score possible was 1,000 points. Detailed information on the fuel economy test has been provided in Chapter 4.

Entrant team scores obtained during CACR testing have been compiled in Table III - 1 on the following page. The value of S has been determined using the formula listed at the top of this page.

Table III - 1

CACR ENTRANT TEAM SCORES

Entrant No.	E	P	R	FE	S
1	0.71	397	976	663	1445
2	0.46	563	991	402	899
3	0.70	410	977	1000	1670
4	1.34	543	1000	822	3169
5	0.87	539	938	806	1986
6	0.55	391	945	419	965
10	0.48	583	993	1000	1236
11	0.65	588	1000	1000	1682
12	1.48	559	912	464	2863
15	0.27	763	960	544	612
16	0.92	434	909	402	1605
17	1.46	475	968	766	3225
18**	1.70	698	996	445	3636
19	0.40	647	831	1000	991
20	0.86	715	954	601	1952
21	0.53	656	997	670	1231
22	0.98	543	1000	1000	2492
23	1.61	504	850	577	3108
24	0.88	664	957	756	2091
30	0.76	629	884	374	1434
31	0.30	607	979	638	667
32	0.18	630	684	845	388
33	0.56	527	970	553	1147
34	0.51	486	1000	1000	1267
35	0.15	562	1000	540	315
36***	0.60	792	1000	977	1661
37	0.56	653	1000	1000	1485
41**	1.04	568	997	819	2479
42	0.39	329	904	1000	870
50	0.09	359	1000	367	155
51	0.60	608	932	781	1392
52	0.36	441	950	1000	860
61	-	88	-	-	-
65**	0.93	378	305	936	1505
66	0.71	397	247	665	929
70	-	133	-	-	-
71*	0.36	292	562	672	549
75*	0.29	473	665	640	518
90**	-	65	420	0	-

*** overall winner
** class winner
* class co-winner, tied for first place

THE CACR CLASS WINNERS

The CACR class winners included six separate vehicle entries representing four different power plant types. One of four teams from Worcester Polytechnic Institute, an LPG-powered Chevy II Nova took honors in the internal combustion engine class, a subdivision of which was the vehicles running on gaseous fuels. Within the same power plant class but representing vehicles burning a liquid fuel, Stanford University's alcohol-powered Gremlin emerged the winner. The Brayton Cycle class (gas turbine) possessed only one entry, a team from the Massachusetts Institute of Technology, which upon the successful completion of cross-country travel automatically became the winner. The electric vehicle category witnessed a neck and neck race between two of the entrant teams; when the final scores had been computed, Cornell University was declared the winner. The electric-hybrid entries from the University of Toronto and Worcester Polytechnic tied for top honors in this particular power plant class. The Rankine Cycle category (steam car) had no winner due to the inability of the entries in this class to successfully complete the race.

On the following pages are presented the technical reports and test data obtained during the competition for the CACR class winners.

Worcester Polytechnic Institute

Entrant: #18

Class: I.C.E. (Gaseous Fuel)

Team Captain: Edward W. Kaleskas
24 Brooks Street
Worcester, Massachusetts 01609

Body and Chassis: 1970 Chevy II Nova, 4-door sedan

Vehicle Weight: 2960 lbs.

Power Plant: I.C.E., 350 C.I.D. Chevrolet propane engine, factory equipped with high temperature valves and seats, and impact extruded pistons.

Transmission: Chevrolet turbohydramatic with kickdown linkage disconnected.

Fuel: Liquefied Petroleum Gas (propane)

Fuel System:

Storage in 35 gallon pressure tank located in trunk. Fuel flows through high pressure hose to the converter. In the converter, fuel is reduced in pressure and vaporized. Vapor then passes to Ensign variable venturi carburetor.

Exhaust System:

Standard single exhaust system, but with two Engelhard catalytic reactors at the exits of the exhaust manifolds.

Emission Control:

1) Catalytic exhaust reactors used to oxidize HC and CO.

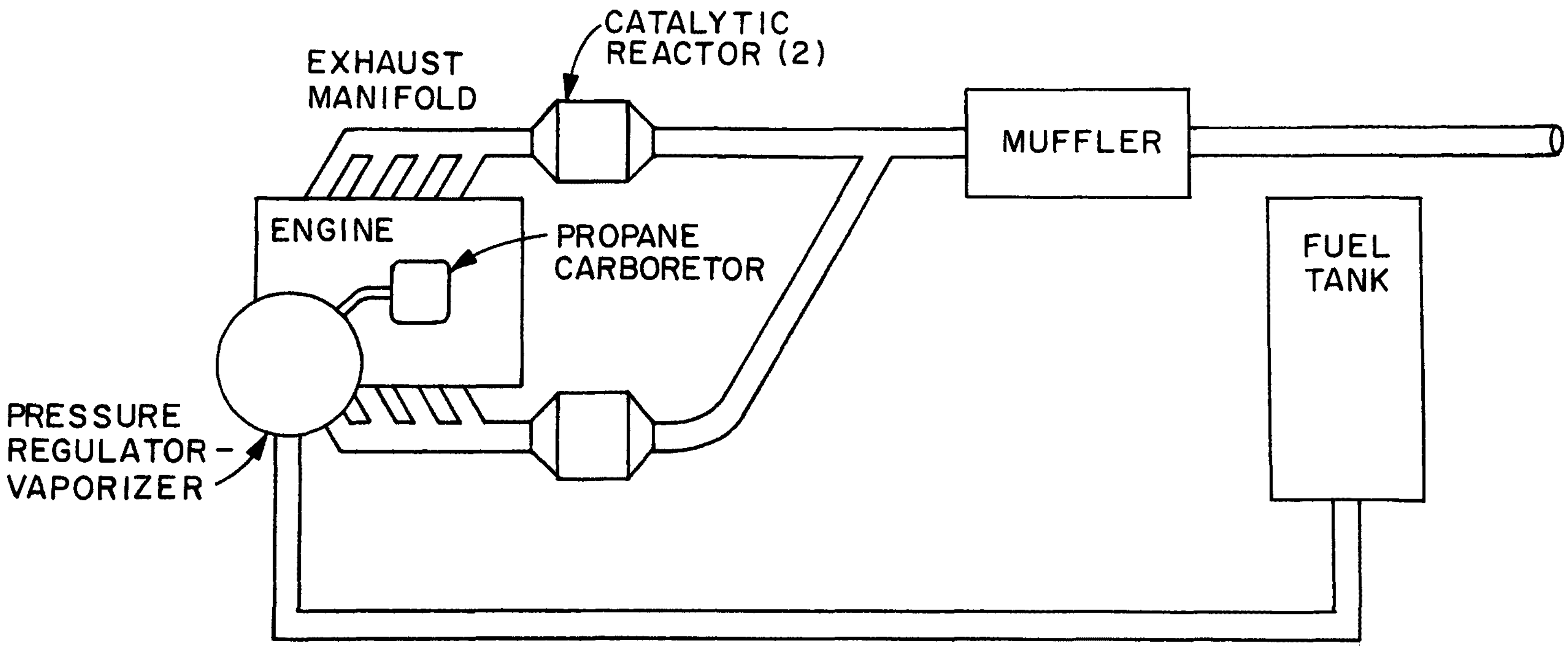
2) Double head gaskets installed to lower compression ratio, thereby lowering flame temperature and reducing NO_x.

3) Ignition timing set at 6° BTDC and vacuum advance eliminated to reduce NO_x.

4) Lean air-fuel ratio (23/1) used to reduce NO_x by lowering flame temperature.

WORCESTER POLYTECHNIC INSTITUTE #18

SCHEMATIC OF FUEL AND EXHAUST SYSTEMS



Performance Data: #18

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	5.6
0-45	8.6
20-50	5.2

2) Braking

Speed (mph)	Stopping distance (ft.)
29	35
53	127

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	75.0
Driver #2	76.8

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	78.0
30 cruise	50'	62.0
Idle	10'	67.5

Emissions Data: #18

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.24	10	20
CO	1.00	1000	1000
NO	0.55	100	100

Part. (gm/mile): 0.02

Fuel Economy: #18

111.2 miles/million Btu

Stanford University

Entrant: 41

Class: I.C.E. (liquid fuel)

Team Captain: Dana G. Andrews
c/o Robert Byer
Hansen Labs
Stanford University
Stanford, California 94301

Body and Chassis: 1970 American Motors Gremlin

Vehicle Weight: 2569 lbs.

Power Plant: I.C.E.; 232 C.I.D. American Motors 6-cylinder engine.

Drive Train: Three-speed manual transmission, 3.08:1 rear axle ratio

Fuel: Methanol (Methyl Alcohol)

Fuel System:

Standard fuel tank retained. Conelec electric fuel pump installed, but malfunction necessitated use of lower capacity stock fuel pump. Zenith model 32 NDIX two-barrel carburetor, mixture heater, and water heated intake manifold installed.

Exhaust System:

Standard system augmented with an Engelhard Diesel Exhaust Purifier (catalytic reactor). Exhaust gas recirculation system installed.

Emission Control:

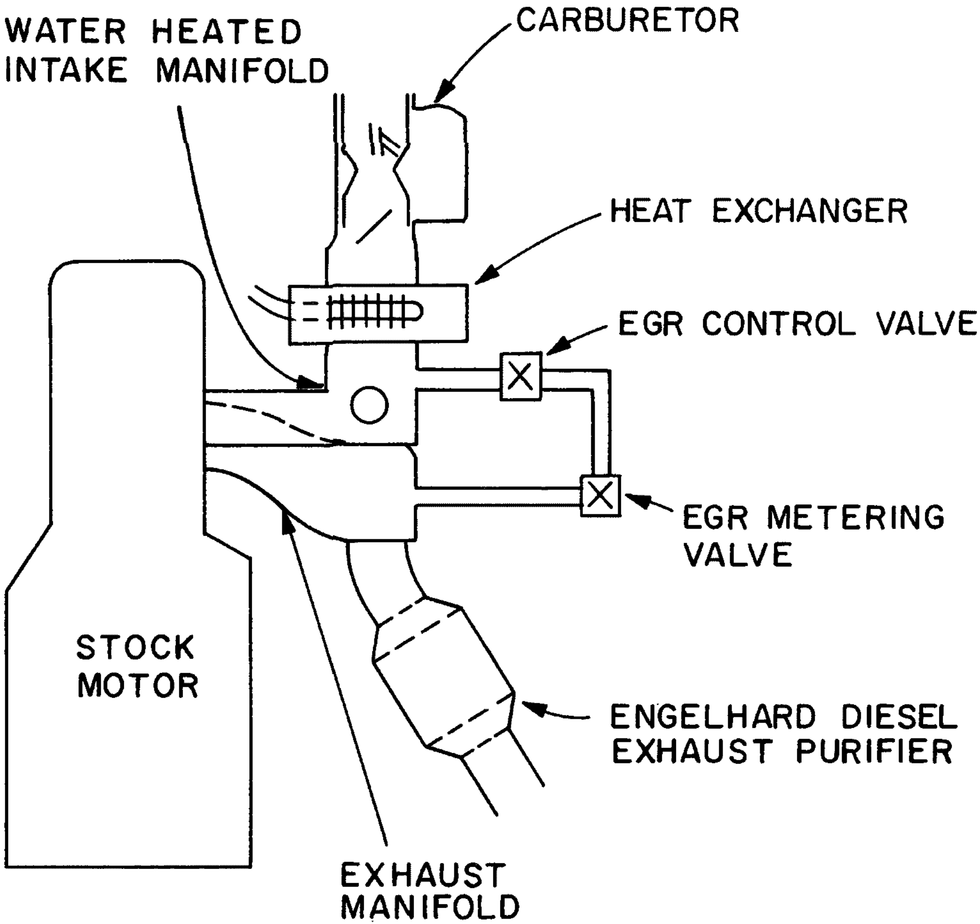
1) Lean air-fuel ratio (8.5:1 at low speeds to 7.5:1 at full throttle) used to reduce HC, CO, and NO_x. Stoichiometric ratio is 6.5:1.

2) Heat exchanger (heated by engine coolant) installed in adapter plate between carburetor and intake manifold. In conjunction with water-heated manifold, this provides better fuel vaporization and distribution, which results in lower HC, CO, and NO_x.

3) Catalytic reactor employed to oxidize HC and CO with excess air provided by lean operation.

4) Exhaust gas from exhaust manifold recirculated into intake manifold to lower NO_x. Hot gases also help vaporize fuel.

EMISSION CONTROL FEATURES #41



Performance Data: #41

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.0
0-45	11.6
20-50	10.2

2) Braking

Speed (mph)	Stopping Distance (ft.)
29	40
50	122

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	83.8
Driver #2	81.0

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	70.5
30 cruise	50'	59.0
Idle	10'	52.0

Emissions Data: #41

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.42	23	44
CO	4.68	1000	2300
NO	0.86	279	116

Part. (gm/mile): 0.02

Fuel Economy: #41

171.0 miles/million Btu

Massachusetts Institute of Technology

Entrant: #90

Class: Brayton Cycle (turbine)

Team Captain: Michael L. Bennett
12 Lawrence Road
Brookline, Massachusetts 02146

Body and Chassis: 1970 Chevrolet C.10 half-ton pickup truck

Vehicle Weight: 5200 lbs.

Power System:

Turbine-Electric configuration. Gas turbine drives an alternator which provides A.C. power to a rectifier system. D. C. power from the rectifier is delivered to a D.C. motor, which drives the rear wheels through the 4.11:1 differential.

1) Turbine - **Airesearch GTP-70-52 gas turbine.** 225 horsepower maximum output, rated at 136 H.P. at sea-level atmospheric pressure and 80°F.

2) Alternator - General Electric model 2CM 357A1. Provides 150 KW, 400 c.p.s. A.C. at 6000 r.p.m.

3) Motor-Inland M-12004-A series wound D.C. Motor. Rated at 100 H.P. continuous, 600 H.P. maximum output.

4) Rectifier - Designed and built by entrant team.

Turbine, alternator, and rectifier are mounted in truck bed. Electric motor is mounted in engine compartment.

Control Features:

Constant motor torque or current control. Turbine and alternator run at constant speed, with output controlled by excitation applied to field windings.

Fuel:

JP-1 or JP-4 (aviation fuel)

Fuel control unit of the turbine is controlled by mechanical, thermal, pneumatic, and electronic feedback units. Fuel tank mounted in bed.

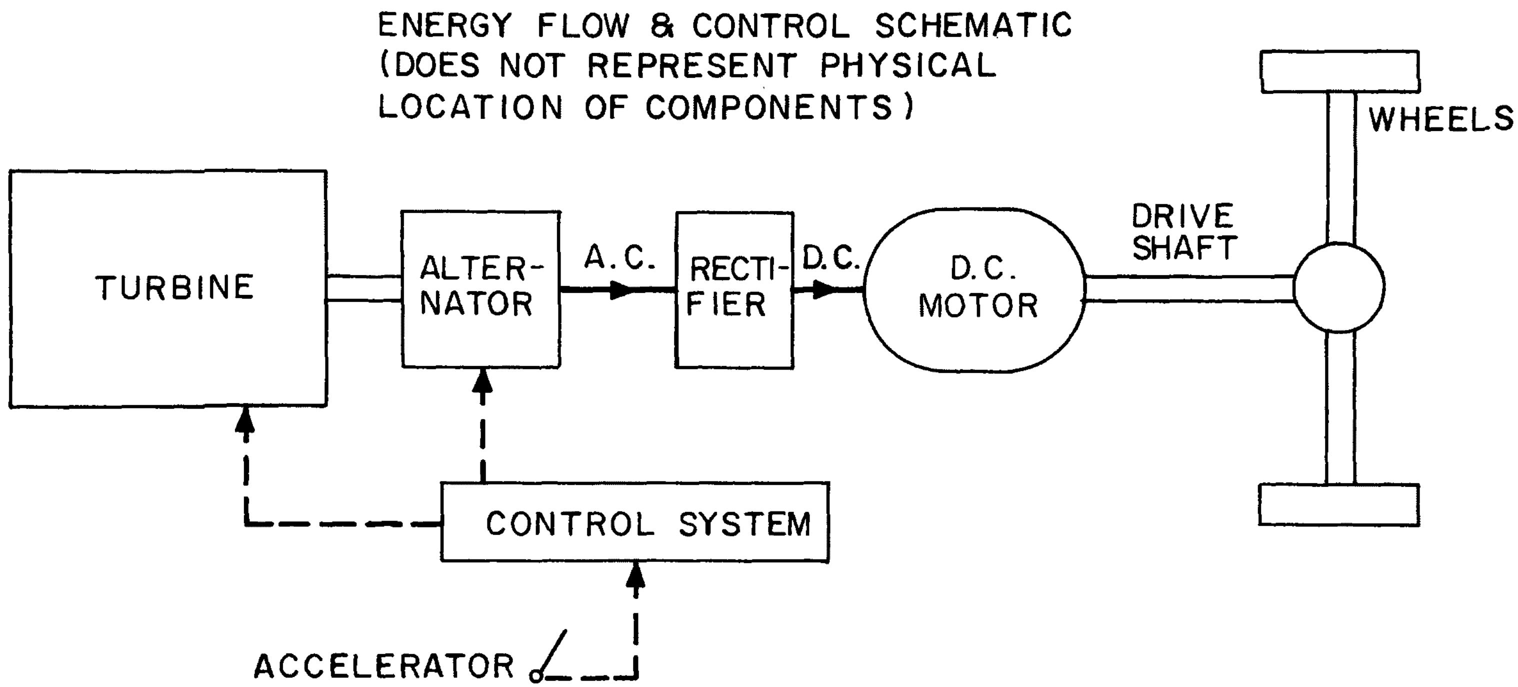
Miscellaneous Features:

1) Heavy-Duty wheels and tires mounted.

2) Aluminum camper shell installed over truck bed to cover turbine, etc.

3) Acoustic intake and exhaust mufflers installed.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY #90



Performance Data: #90

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	12.0
0-45	27.1
20-45	21.0

2) Braking

Speed (mph)	Stopping distance (ft.)
28	44
47	133

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	114.0
Driver #2	110.6

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	89.5
30 cruise	50'	89.5
Idle	10'	105.0

Emissions Data: #90

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	5.73	no data	no data
CO	78.50	no data	no data
NO	6.24	no data	no data

Part. (gm/mile): No data

Fuel Economy: #90

24.0 miles/million Btu

Cornell University

Entrant: #65

Class: Electric

Team Captain: Mark Hoffman
224 Phillips Hall
Cornell University
Ithaca, New York 14850

Body and Chassis: American Motors Hornet

Vehicle Weight: 5311 lbs.

Power Plant: Electric motor, D.C. four pole configuration. 20 H.P. continuous rating, with overlaod capacity to 120 H.P.

Drive Train: Standard Hornet 3-speed manual transmission, driveshaft

Energy Storage:

Battery pack consisting of 24 six-volt Electric Fuel Propulsion lead-cobalt (variation of lead-acid) batteries. 34 kilowatt-hour capacity.

Power Control:

"3 in 1" dual chopper: circuitry which pulses battery voltage to the motor. Even harmonics of chopper frequency are cancelled, reducing A.C. component and, therefore, heat losses in the motor. Pulse width and frequency are modulated to control motor speed.

Chopper also functions as regenerative braking control. Motor acts as a generator when accelerator is released. Pressing brake pedal brings regenerative braking to its maximum, and actuates the hydraulic brakes. Power generated by this process is returned to batteries.

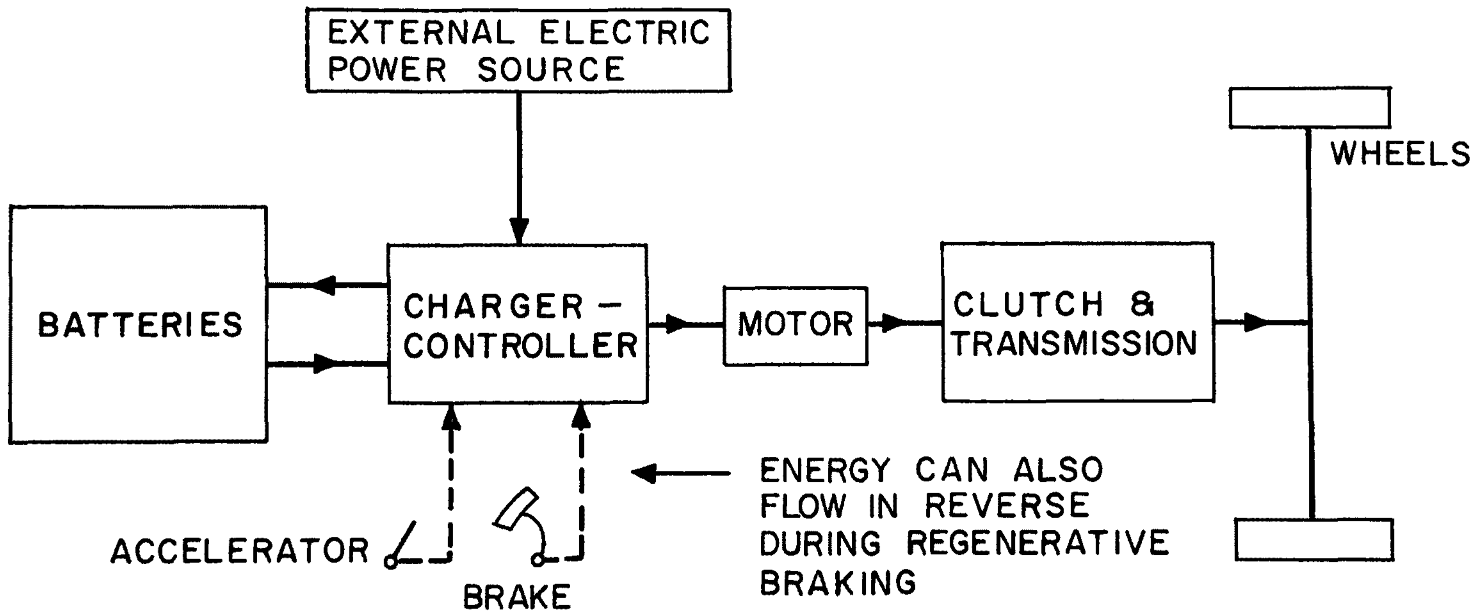
Due to last-minute problems, the 3-in-1 dual chopper was not used during the Race. A ten-step series-paralled contactor controller was used as a substitute. This controller provided levels of 12, 24, 36, 72, 108, and 144 volts to the motor, with a motor field weakening step after each of the last four voltage levels.

Recharging Scheme:

On-board charger can accept 208 to 240 volts single-phase A.C., three-phase A.C., or D.C. and can supply up to 500 amps to the battery pack. Charger regulation includes voltage, current, temperature, and gassing controls.

CORNELL UNIVERSITY #65

ENERGY FLOW DIAGRAM



Performance Data: #65

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	8.5
0-45	18.4
20-40	14.0

2) Braking

Speed (mph)	Stopping distance (ft.)
30	61
49	186

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	89.8
Driver #2	87.8

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	62.0
30 cruise	50'	61.0
Idle	10'	Not applicable

Emissions Data: #65

Not applicable.

Fuel Economy: #65

189.8 miles/million Btu*

Electrical Efficiency: #65

1.85 miles/kilowatt-hour

*includes correction for power plant efficiency of 35%

Worcester Polytechnic Institute

Entrant: #71

Class: Electric-I.C.E. Hybrid

Team Captain: Steven Clarke
Mechanical Engineering Department
Worcester Polytechnic Institute
Worcester, Mass. 01609

Body and Chassis: 1970 American Motors Gremlin

Vehicle Weight: 4740 lbs.

Power Plant: General Electric type BY401, 25 H.P., series wound direct current traction electric motor. Battery pack rated at 200 amp-hours at 20 hour rate.

Drive Train: Jeep drive shaft, heavy duty 5:1 ratio differential

Batteries:

Twenty Exide type 3EC-19, 6 volt lead-acid batteries, connected in series for 120-volt power. Battery pack rated at 200 amp-hours at 20 hour rate.

Power Control:

Modified General Electric model 300 SCR controller. Full battery voltage applied to motor in pulses. Speed and torque controlled by varying pulse frequency through foot-pedal potentiometer. Pulsing circuit by-pass provided for top speed operation.

Recharging Scheme:

Batteries charged with current supplied by a General Electric tri-clad brushless synchronous generator. The generator is driven by an internal combustion engine. Control curcuits allow the batteries to accept charge during low-power vehicle operation, or deliver power at greater loads. The generator can provide 25 KVA of 3-phase A.C. power, which is rectified to provide D.C.

Engine:

Jeep Dauntless V-6 I.C.E.

Emission Control:

1) Englehard catalytic reactors installed just downstream of exhaust manifolds to oxidize HC and CO.

2) Air injection on exhaust manifolds to provide oxygen for reactors.

3) Exhaust gas recirculation to lower NO_x emissions.

Vehicle Modification:

1) Suspension stiffened by installing coil and leaf springs from an A.M. ambassador, and adding Booster coils to the shock absorbers.

2) Goodyear 15 inch radial tires and wheels to match installed.

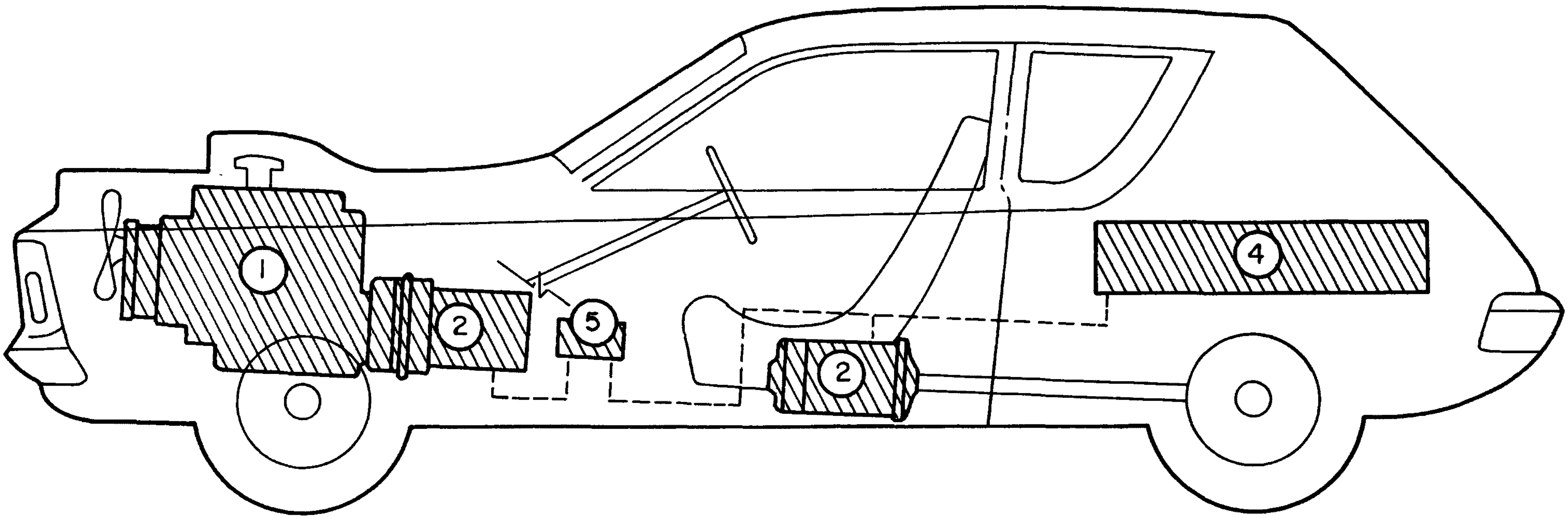
3) Rear seat removed to make room for battery pack.

4) Ten-inch brake drums installed.

5) Hood Modified (raised) to provide clearance for engine components.

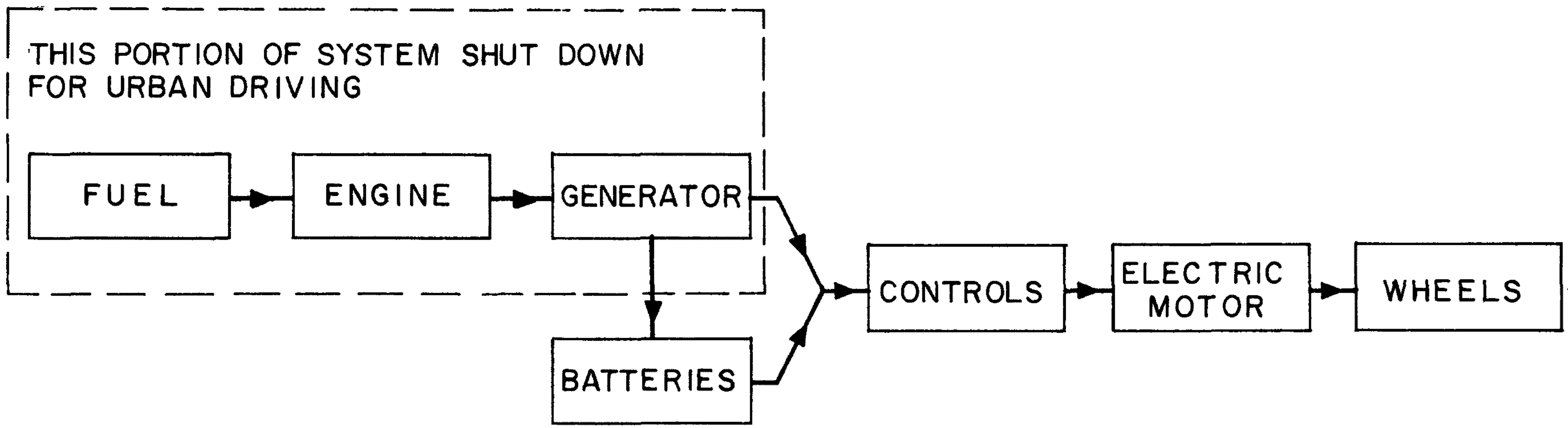
6) Instruments include tachometer, speedoment, odometer, water temperature gauge, oil pressure gauge, alternator voltmeter and ammeter, motor voltmeter and ammeter, and watt hour meter.

WPI - ELECTRIC HYBRID



1. DAUNTLESS V-6 ENGINE
2. GE AC SYNCHRONOUS GENERATOR
3. GE DC MOTOR
4. 20 SIX VOLT EXIDE BATTERIES
5. SOLID STATE CONTROLS

ENERGY FLOW DIAGRAM #71



Performance Data: #71

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	17.2

2) Braking

Speed	Stopping distance (ft.)
46	153

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	106.0
Driver #2	104.5

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	67.5
30 cruise	50'	59.5
Idle	10'	49.5

Emissions Data: #71

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.59	27	20
CO	1.67	1000	1500
NO	6.09	1041	1000

Part. (gm/mile): No data

Fuel Economy: #71

147.6 miles/million Btu

University of Toronto

Entrant: #75

Class: Electric-I.C.E. Hybrid

Team Captain: Douglas Venn
Mechanical Building
University of Toronto
Toronto 5, Ontario
Canada

Body: Fabricated fiberglass

Chassis: Custom built-constructed from 1970 Chevelle front end and 1967 Corvair transaxle and rear suspension.

Vehicle Weight: 4160 lbs.

Power System:

Propane-fueled I.C.E. used as prime mover, transmitting power through an electric power system, or mechanically through a drive shaft, or in parallel with electric drive. Electric drive may also be used on battery power with I.C.E. shut down.

Electric Drive - Two Delco 12 KW motor-generators. One (used as motor) drives the main driveshaft by a belt drive, the other (used as a generator) is mounted forward and driven by the engine. Ten 90 amp-hour lead-acid batteries used for electric energy storage.

Electric power controlled by an SCR chopper with automatic control logic circuitry.

Engine:

302 C.I.D. Chevrolet V-8, modified to run on propane.

Transmission:

4-speed manual (Corvair transaxle)

Fuel System:

Propane tank in rear of vehicle. Two Algas gaseous carburetors feed into a split plenum chamber which is mounted on a Weber intake manifold. Balance line between plenum chambers provides uniform vacuum and better mixture distribution.

Exhaust System:

Dual system with regular manifolds. A platinum catalytic reactor and a conventional muffler followed each manifold, in the order given.

Emission Control:

1) Engine intake and exhaust ports were ported and polished. Larger, high temperature, valves were installed. Displacement of each upper combustion chambers rendered precisely the same. These modifications provide better and more uniform breathing characteristics.

2) Catalytic reactors installed to oxidize HC and CO.

Additional Modifications:

1) Compression ratio raised from 7.1:1 to 11:1 to achieve more complete combustion in the cylinders and lower exhaust temperature.

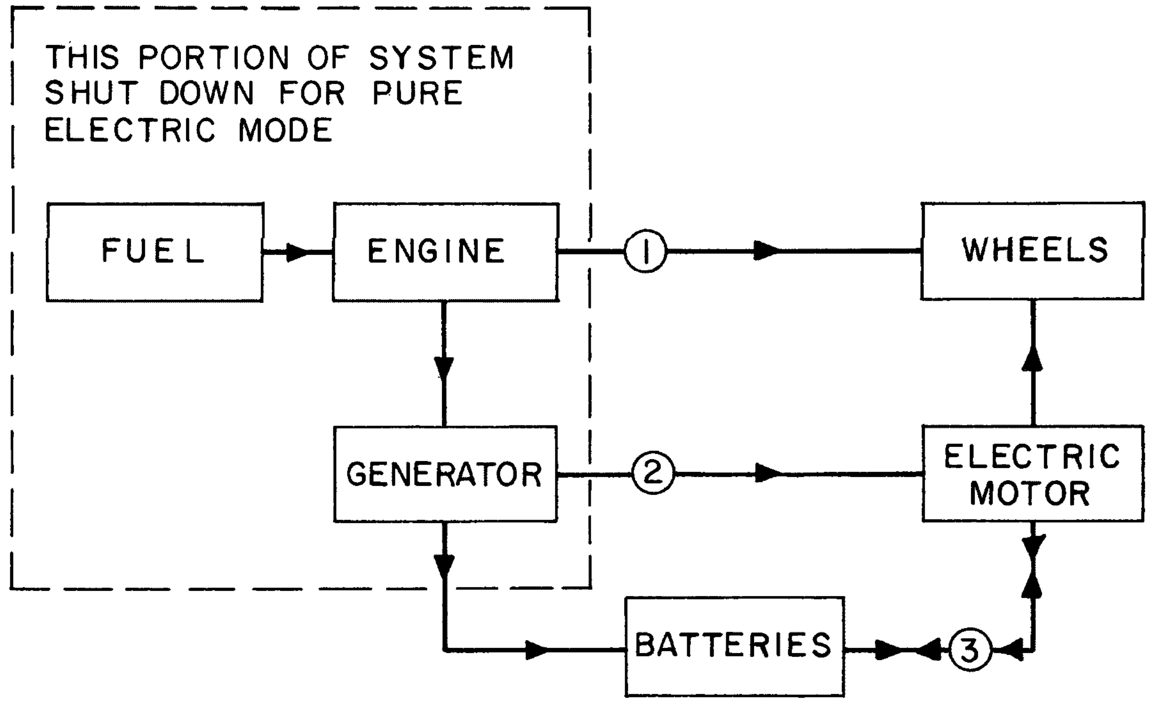
2) 1965 truck hydraulic lifter camshaft with short duration (252°) and later opening and closing times installed.

3) Scintilla vertex magneto ignition system installed.

4) Dual electric fans installed to assist regular belt-driven fan in cooling the 1970 Buick radiator.

5) Aluminum wheels and Dunlop six-ply radial 185 x 15 tires installed.

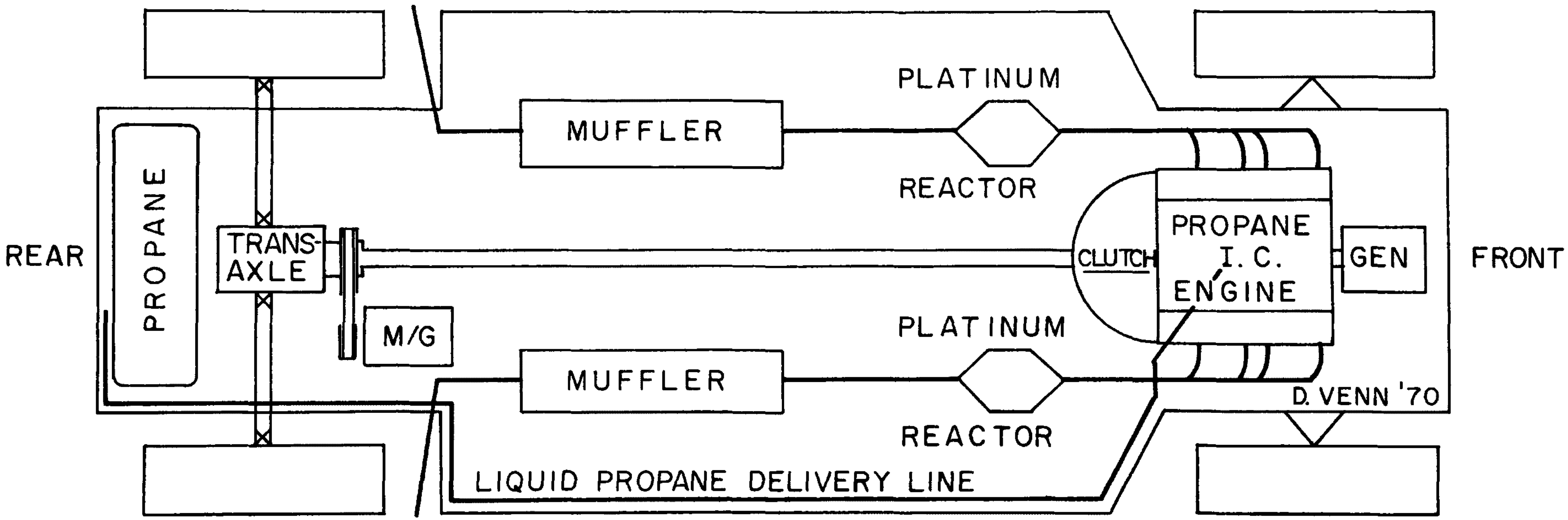
ENERGY FLOW DIAGRAM #75



Four Driving Modes

1) Direct drive: Energy flows through path 1 only.
2) Indirect-electric: Energy flows through path 2 and 3.
3) Pure electric: Energy flows through path 3 only.
4) Parallel: Energy flows through path 1, 2 and 3.

SCHEMATIC OF DRIVE LINE, PROPANE SUPPLY AND EXHAUST SYSTEM #75



Performance Data: #75

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.3
0-45	12.4
20-50	10.6

2) Braking

Speed (mph)	Stopping distance (ft.)
27.0	35
49.5	131

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	80.8
Driver #2	78.5

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	82.0
30 cruise	50'	72.0
Idle	10'	66.5

Emissions Data: #75

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	2.59	58	46
CO	1.06	1000	1000
NO	2.35	336	615

Part. (gm/mile): 0.01

Fuel Economy: #75

143.8 miles/million Btu

THE CACR OVERALL WINNER

As was stated earlier, a judging panel selected the overall winner of the CACR competition. The five panel members who contributed their time and energies in this singularly important capacity were as follows:

Dave Ragone	Dean, Thayer School of Engineering
Bill Gouse	Executive Office of the President, Office of Science and Technology
John Brogan	Director, Division of Motor Vehicle Research and Development; National Air Pollution Control Admin.
Harry Barr	President, Society of Automotive Engineers
John Maga	Executive Secretary, California Air Resources Board

Prior to the competition, the committee had instructed the panel to select that CACR test vehicle which exhibited the best potential as a solution to the problem. In order to allow complete flexibility, they were not bound by the scoring formulae set forth in the CACR Rules.

The Wayne State entry was judged the winner by the panel on the strength of the overall quality of engineering, the written and oral presentations made by the students involved, and its potential applicability to the solution of the national automotive air pollution problem.

Knowing that the Wayne State car did not perform particularly well in the Detroit cold-start test, Dr. Ragone, upon investigation, found that the manual choke wire had been left in the out-position during the first two cycles of this test due to a driver error. The last five cycles in the Detroit test showed the car's emissions to be excellent, but could not be used to determine how low the vehicle's emissions actually were since the first two cycles are of critical importance in the cold-start test. Subsequent to the Race, the car was tested at the NAPCA facility in Los Angeles and was found to be very close to the 1980 Federal standards on the basis of a 4 hour soak, cold-start, CVS test. This, in some sense, is an indication of the potential of this particular design, and should substantiate the selection of the overall winner.

Presented on the following three pages are a synopsis of the Wayne State technical report and the test measurements made upon the vehicle during and after the CACR competition.

Wayne State University

Entrant: #36

Class: I.C.E. (Liquid Fuel)

Team Captain: Richard Jeryan
18261 Forrer
Detroit, Michigan 48235

Body and Chassis: 1971 Ford Capri

Vehicle Weight: 2300 lbs. (approximately)

Power Plant: I.C.E.; 302 C.I.D. Ford V-8

Drive Train: Ford C-4 automatic transmission, 2.33:1 rear axle ratio

Fuel: Unleaded gasoline

Fuel System:

Polyethylene fuel tank (18 gal. capacity) with an in-tank electric fuel pump installed. Insulated fuel lines led to modified carburetor. Mechanical fuel pump retained for emergency use.

Exhaust System:

Conventional manifolds. Two Engelhard PTX-5 catalytic reactors installed below each manifold. Air introduced below the first set (before the second set) of reactors. Dual pipe combines, then enters conventional muffler.

Emission Control:

1) Vehicle weight reduced to lower power demand, thereby lowering total emissions, improving fuel economy and performance.

2) Low valve overlap(11°) camshaft installed to reduce hot residual gases in cylinder and allow more cold exhaust gas recycle. This lowers peak combustion temperature which reduces NO_x emissions.

3) Combustion chambers contoured to reduce "dead" (non-burning) volumes, which reduces HC emissions.

4) Projections on the head and piston were removed to eliminate hot spots, thereby reducing NO_x formation.

5) Time constant of Vacuum spark advance system increased to lower transient emissions.

6) Exhaust gas recirculation system employed to lower NO_x emissions. Vacuum override system connected to spark advance line prevents recycle when spark vacuum is below 4 or above 20 inches of mercury.

7) Air-fuel ratio stabilized between 14.5:1 and 15:1 by carburetor air and fuel temperature control features. Air temperature controlled by temperature-sensitive valve which mixes high and low temperature inlet air. Fuel lines insulated, and carburetor insulated from engine heat. Close air-fuel ratio control allows catalytic exhaust reactors to function at maximum efficiency.

8) Dual power valve system added to carburetor to reduce bore-to-bore imbalance, providing additional control of air-fuel ratio.

9) PCV valve replaced by .076 inch orifice to reduce effect of varying crankcase flow rate on air-fuel ratio.

10) First set of catalytic reactors employed to reduce NO_x.

11) Second set of reactors, in conjunction with air injection, installed to oxidize HC and CO.

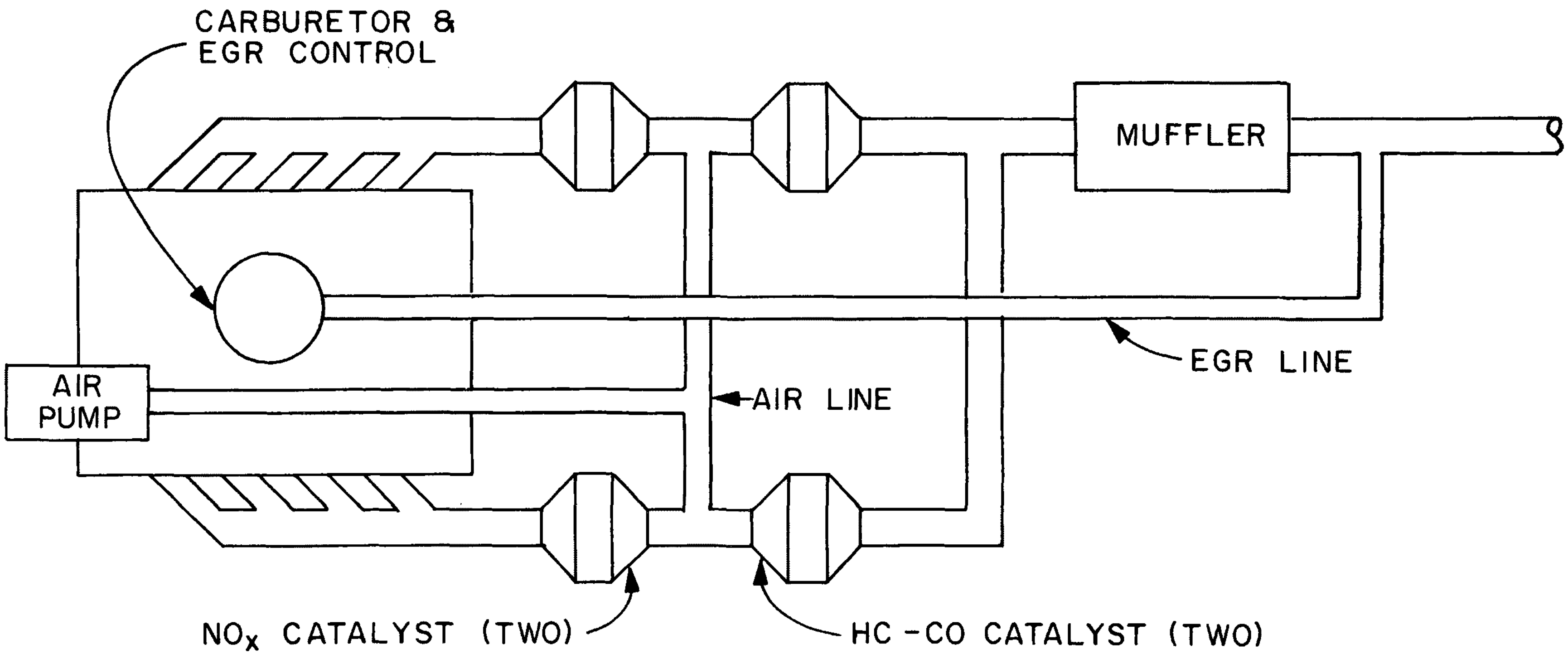
Miscellaneous Modifications

1) Hardened valve seats installed.

2) Oil pan and pump, front end belt drives modified to facilitate engine installation.

3) Extra-capacity radiator installed, and extra air ports cut in front sheet metal.

EXHAUST SYSTEM DIAGRAM #36



Performance Data: #36

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	3.6
0-45	5.2
20-50	4.2

2) Braking

Speed (mph)	Stopping distance (ft.)
35	59
53	124

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	69.4
Driver #2	68.6

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	73.0
30 cruise	50'	63.0
Idle	10'	59.0

Emissions Data: #36*

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	1.21	10	16
CO	13.76	1000	1000
NO	0.70	100	118

Part. (gm/mile): 0.04

Fuel Economy: #36

196.3 miles/million Btu

* These data recorded for official C.A.C.R. tests. Unofficial post-race data are recorded on the following page.

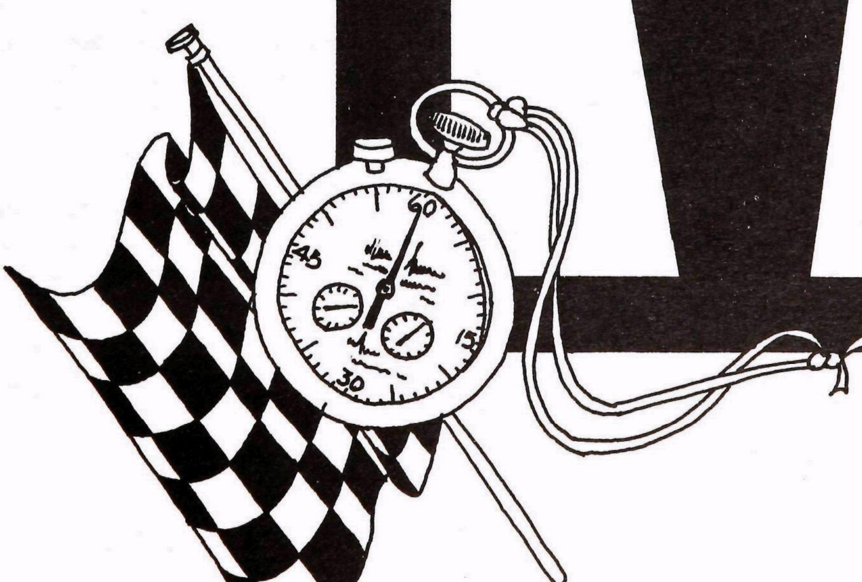
Unofficial post-race emissions data: #36

After the official race events had been concluded, the Wayne State vehicle was emissions tested at APCO (NAPCA) facilities. The test procedure used was the 1970 Federal Test Procedure, which employs the LA-4 driving cycle and constant volume sampling. A four-hour cold soak was used for this test. The results were:

HC	0.19	gm/mile
CO	1.48	gm/mile
NO	0.29	gm/mile*

* Uncorrected for humidity and NO_2 expression.

IV



IV. PERFORMANCE TEST PROCEDURES FOR CACR VEHICLES

INTRODUCTION

Long before the CACR was ever conceived, there existed vehicles which were very low polluters. The original electric cars of the early 1900's were clean and quiet, but were eventually replaced by the internal combustion engine (ICE) primarily because they could not match its superior performance. Steamers could deliver the necessary power for the desired roadway performance but the power plant was necessarily larger and more expensive.

In the search for a cleaner auto, the organization committee felt that any reasonable effort could not make large compromises in the areas of vehicle safety and performance. It was decided that three specific vehicle characteristics should be measured as the major performance indicators, these being acceleration, braking, and general handling and maneuverability. In addition, noise level testing would be included under the heading of vehicle performance for scoring purposes, although it is not a performance factor in the usual sense. Although we were concerned about each vehicle's safety features and general roadworthiness, we found no practical way to incorporate safety into the scoring formulae. Consequently, the rule was made that all entries must comply with the Massachusetts State vehicle inspection standards.

PRELIMINARY SETUP

All performance testing was done at the M.I.T. Flight Facility, Hanscom Field in Bedford, Mass. The testing area included an airplane hangar, a large paved apron, and a 2000-foot taxiway. A standard inspection station was set up in the hangar by two officers from the Mass. Registry of Motor Vehicles. Major items to be checked included lights, steering, exhaust systems, ball joints, and brakes. The inspections were conducted on all test vehicles during the morning of that day on which they were to be performance tested.

Due to space limitations, all tests could not be run concurrently. Each day was divided into three blocks of time; the first being reserved for noise level measurements, the second for acceleration-braking, and the third for the road handling tests.

THE NOISE MEASUREMENT TEST

The noise level tests were conducted by Bolt, Beranek, and Newman, Inc., (B.B. & N.) an acoustical consulting firm under contract with the Federal government's Department of Transportation. Part of the measurement procedure was taken from SAE J-986a, a standard test procedure for passenger cars and light trucks; three additional tests were established by the committee, in consultation with Mr. Charles Dietrick of BB & N. The four situations were as follows:

1. the test vehicle at 30 miles per hour (mph), wide open throttle (30 WOT)
2. the test vehicle at 30 miles per hour (mph), cruising
3. the test vehicle at 60 miles per hour (mph), cruising
4. the test vehicle in a stationary position with motor idling.

The layout of the test area, vehicle path, and microphone placement described in SAE J-986a were used for all moving tests. The CACR entrant vehicles were driven in a straight line past a microphone which was placed fifty feet from the travel lane. First, the noisier side of each vehicle was established by having the car cruise past the mike in each direction at 30 mph. Thereafter, all noise measurements for each test were made from the noisier side.

The 30 mph wide open throttle (30 WOT) test was conducted in a 50-foot long test "trap", the center of which was directly opposite the microphone. Each vehicle entered the trap at 30 mph, then accelerated at full throttle in the lowest gear for which maximum or "red line" engine speed would not be exceeded within the trap. The vehicle was required to continue accelerating in the same gear for another 100 feet after leaving the trap, unless maximum engine speed was reached, at which point the throttle was feathered to avoid excess engine speed.

The 30 mph cruising test required the vehicle to traverse the trap at a constant 30 mph speed in the normal road gear. The 60 mph cruising test was identical, except for the speed.

The idle noise measurement was taken at a distance of 10 feet, with the vehicle stationary and idling, if the vehicle engine possessed such a mode of operation.

Several days of rain during the pre-race week of testing made it necessary to delete the 60 mph cruising test for noise. Thereafter, each car completed both of its moving noise tests in turn, and then all cars were tested at idle.

Noise levels were recorded on a dB(A) scale, which includes frequency compensation, and converted to point scores using the scoring curve illustrated in Figure IV-1 on the following page.

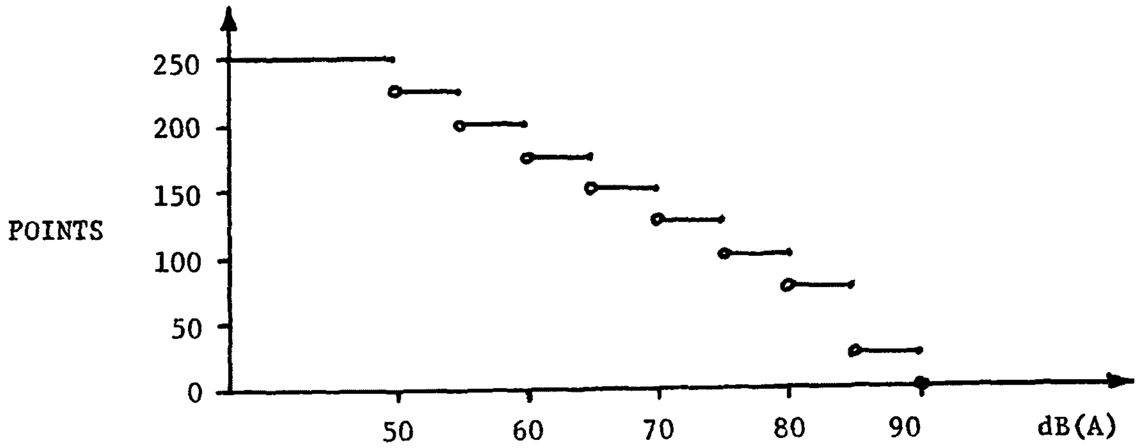


Fig. IV - 1: Scoring curve used for all noise measurement tests.

The point scores for the three test situations were then averaged to give the final noise score.

THE ACCELERATION TEST

It was decided that three ranges of vehicle acceleration should be measured in order to simulate only a few of several possible situations in urban traffic. The acceleration modes measured included:

1. 0 to 30 mph
2. 0 to 45 mph
3. 20 to 50 mph

For each speed range, the elapsed driving time between the designated speeds was measured, and an average rate of acceleration was computed by the committee in units of g, where one g equals 32.2 feet per second^2 ($1g = 32.2\ ft/sec^2$).

The measurements of speed versus time were at first taken by attaching a fifth wheel to the rear of each vehicle and recording the output on a properly calibrated strip chart recorder, mounted within the vehicle. An accelerometer was mounted on each vehicle and its output simultaneously recorded on another track of the strip chart.

The accelerometer output was not used to compute acceleration, but only to establish the exact point in time at which acceleration began. The starting point was taken as the first point at which a non-zero acceleration was recorded. Time was measured from this point to the point at which the specified terminal speed was reached. For the 20 to 50 mph test, time was measured between the point at which 20 mph was registered on the strip chart and the point at which 50 mph was reached.

The rate of average acceleration for each speed range was computed using the following standard kinematic equation:

$$a = c_1 \frac{(V_2 - V_1)}{t}$$

where a = acceleration computed in units of g

v_1 = the vehicle initial speed in mph

v_2 = the vehicle terminal speed in mph

t = the elapsed time in seconds

$c_1 = .0455 = \frac{22 \text{ ft/sec}}{15 \text{ mph}} \left(\frac{1 \text{ g}}{32.2 \text{ ft/sec}^2} \right)$

a dimensionless constant.

Due to an unfortunate accident (the fifth wheel dropped off of a vehicle during a trial run),only six vehicles completed testing using the fifth wheel, accelerometer, and strip chart recorder arrangement. These teams included entrants 31, 34, 35, 42, 50, and 52. Thereafter, a radar unit and stopwatches had to be used to measure vehicle speed and elapsed time respectively. Each car was given a hand signal to start, and timed by three stopwatches for the three speed ranges tested. The elapsed time corresponding to each speed range was then recorded, and the average rate of acceleration was computed by the same formula as shown above.

Some doubts were raised by several entrants as to the accuracy and consistency of comparing measurements which had been obtained by using two different techniques and sets of test equipment. This matter will be further discussed in the evaluation section at the end of this chapter.

An unweighted time average of the three acceleration measurement values was computed for each entrant team, and an acceleration score was subsequently assigned using the scoring curve illustrated below:

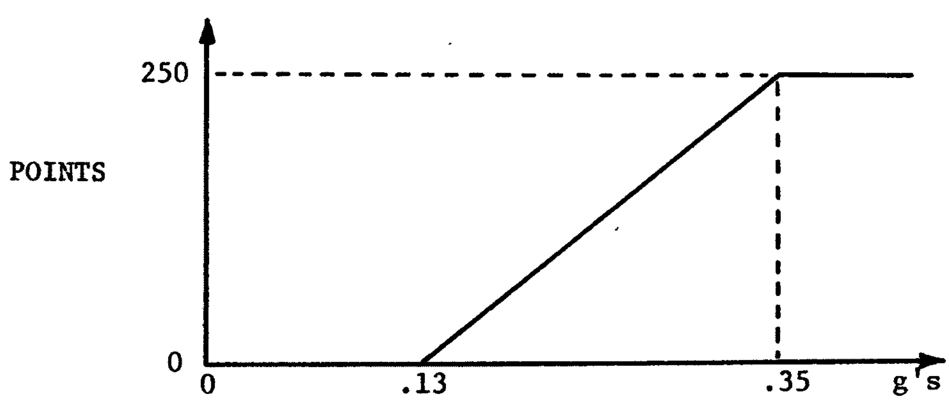


Fig. IV - 2: Scoring curve used in the vehicle acceleration test.

or using the equivalent mathematical equation:

$$P_a = \begin{cases} 0, & \text{if } a \leq .13g \\ \frac{250}{.22}(a - .13), & \text{if } .13g < a < .35g \\ 250, & \text{if } a \geq .35g \end{cases}$$

where P = points

a = average acceleration rate computed in units of g.

The acceleration values of .13g and .35g were chosen as the "break points" of the scoring curve on the basis of consultation with auto testing experts at the Cornell Aeronautical Laboratories in Buffalo, New York. These values were felt to be the minimum acceptable and maximum necessary average acceleration rates, respectively, for a vehicle traveling in today's urban traffic. The lower limit of .13g corresponds to 0 to 30 mph in 10.5 seconds, which is comparable to many foreign and domestic economy cars. The upper limit of .35g corresponds to 0 to 30 mph in 3.9 seconds, which is slightly better than the average Detroit production model V-8.

THE BRAKING TEST

Vehicle braking performance was tested for a controlled stop situation from two speeds:

1. 55 to 0 mph
2. 30 to 0 mph

The first test was originally planned for 60 to 0 mph, but there was an insufficient length of track for many of the vehicles to accelerate and reach 60 mph before beginning to brake. When each car had attained the designated speed, it entered a 300 foot-long by 12 foot-wide braking lane demarcated by pylons. Once inside the lane, the driver applied the vehicle's brakes with the objective of stopping in the minimum distance without hitting any pylons.

For each braking run the actual vehicle speed was measured by radar, since automobile speedometers can vary widely in accuracy. The stopping distance traveled by each test vehicle during braking was measured, and an average rate of deceleration was computed using the following kinematic formula:

$$a_d = C_2 \frac{V^2}{2S}$$

where a_d = average deceleration rate computed in units of g

V = vehicle speed before braking in mph

S = stopping distance in feet

$$C_2 = .0668 = \frac{22\ \text{ft/sec}}{15\ \text{mph}} \left(\frac{1\ \text{g}}{32.2\ \text{ft/sec}^2} \right),$$

a dimensionless constant.

N.B. This formula computes the distance average of deceleration, not the time average.

The exact point at which the brakes were applied was marked by a chalk "gun" which blasted a chalk mark in the roadway pavement as soon as the driver touched the brake pedal. The stopping distance of the vehicle was measured from this chalk point to the final position of the gun after the car had come to rest.

The deceleration values computed for each stop were then averaged together and a score was assigned to each entrant team using the curve illustrated below:

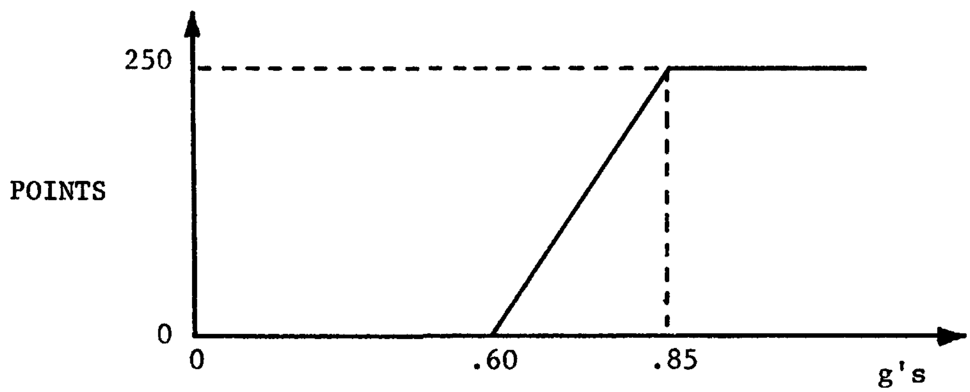


Fig. IV - 3: Scoring curve used for the deceleration measurement.

or using the following mathematical equivalent:

$$P_{a_d} = \begin{cases} 0 & \text{if } a_d \leq .60 \\ \frac{250}{.25}(a_d - .60) & \text{if } .60 < a_d < .85 \\ 250 & \text{if } a_d \geq .85 \end{cases}$$

where P = points

a_d = average deceleration rate computed in units of g.

Again, the break points of .60 g and .85 g were chosen on the basis of what is minimally acceptable and generally available, respectively.

Only one stop at each test speed was recorded for each vehicle, due to severely limited time and space availability. Acceleration and braking tests were run concurrently for each car in order to save time and make the most efficient use of the speed monitoring equipment.

The fifth wheel and strip chart recorder were used to make the braking test measurements for entrant teams 31, 34, 35, 42, 50, and 52. All others were tested with radar.

MEASUREMENT OF GENERAL ROADWAY HANDLING AND MANEUVERABILITY

The handling characteristics of the CACR vehicles were evaluated by timing them on runs through a gymkhana, or "urban driving cycle" (UDC) as it was customarily called during the pre-race activities. The UDC consisted of a driving course demarcated by pylons on the runway and apron area and was set up according to guidelines provided by the Sports Car Club of America in its definition of a gymkhana. It included two U-turns, an "emergency" lane change, a stop and back-up situation, several large-radius turns, a straight-away stretch, and a serpentine series of short linked turns. The general layout of the UDC has been depicted below.

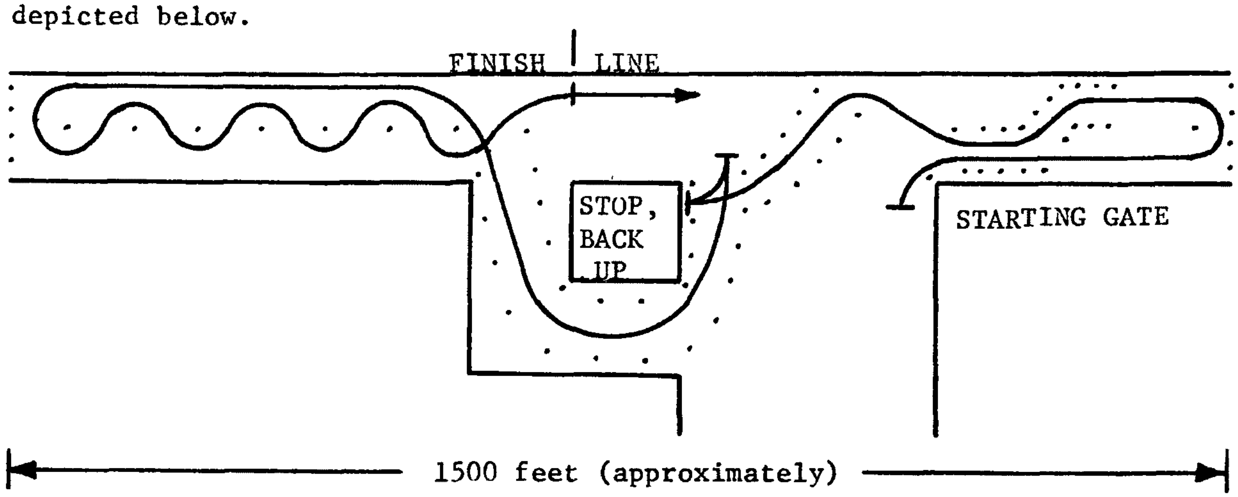


Fig. IV - 4: The urban driving cycle course layout at Hanscom Field in Bedford, Massachusetts

Each vehicle was started at a distance of approximately 3 feet from the starting gate. The stopwatch began clocking time as the front of the car entered the gate. The driver then continued on through the course as quickly as possible. Time was stopped as the front of the car crossed the finish line.

Each vehicle was required to have two separate drivers from the respective team for this event, and each driver was in turn allowed three runs through the UDC. A penalty of 2 seconds was added to a driver's time score for each pylon knocked over during the run. If the driver went off-course, or "washed out", no time was recorded and the run was aborted.

The best recorded time for each driver was selected after all runs had been completed, and times were then averaged for each two-man team to vehicle run time against the scoring curve illustrated below.

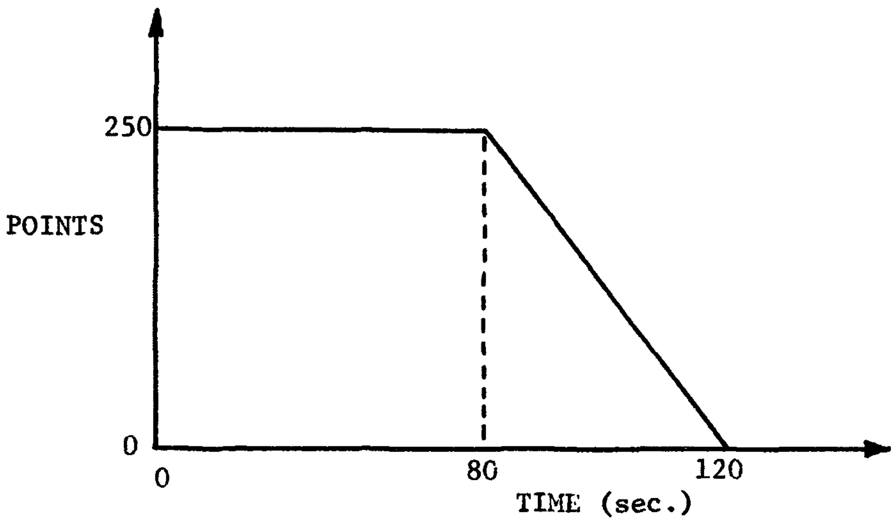


Fig. IV - 5: Scoring curve used for urban driving cycle.

The mathematical equivalent of the UDC scoring curve is as follows:

$$P_{UDC} = \begin{cases} 0 & \text{if } t \geq 120 \\ 750 - \dfrac{250t}{40} & \text{if } 80 < t < 120 \\ 250 & \text{if } t \leq 80 \end{cases}$$

where P = points

t = team average run time computed in seconds.

Original plans called for three drivers per vehicle, but the tight schedule forced a cutback to two. The purpose of having several drivers per vehicle, and three runs per driver was to minimize the effects of driver skill. The performance characteristic to be measured was the inherent handling quality of the car.

The break point of the scoring curve were established by driving a 1970 Ford station wagon through the course several times and then estimating acceptable minimum and maximum times.

GENERAL OBSERVATIONS AND COMMENTS ON THE HANSCOM FIELD PERFORMANCE TESTS

Both during and after the race, it was apparent that several areas of weakness had existed in conducting the performance testing. The most notable of these was the limited amount of data collected for each test situation, with the exception of the noise level testing. Another was the use of two different methods of speed and time measurement for the acceleration and braking runs. Driver skill might also have introduced inconsistencies into the UDC and braking test runs. It would be best to discuss each of these separately.

Ideally, each vehicle should have been run several times through each test situation, and then only the best results from each should have been used for scoring purposes. For example, three or four acceleration runs should have been sufficient to establish the maximum capabilities of the vehicle, whereas most of the race vehicles were allowed only two acceleration runs, and improvements of up to 15% were noted. It is reasonable to suspect that further improvement might have resulted from more test runs.

Similarly, at least three stops at each braking speed (instead of the one conducted during CACR performance testing) would have given a much better picture of the actual mechanical limits of the car. For testing purposes of this type, sufficient time should be allowed between stops for brakes to cool.

Driver skill can certainly affect a car's performance in acceleration, braking, and handling. The driver must know exactly when to shift, how hard he can apply the brakes without losing control, how to judge the best speed and line going into a turn-in short, how to drive the car to its maximum capabilities and always be just below the threshold of losing control. An experienced professional test driver would have been helpful in obtaining optimum performance data from most of the CACR vehicles. In retrospect, the best arrangement might well have been to conduct the tests using both the entrant teams and a professional as drivers, and then computing the best average score.

After the accident which damaged the fifth wheel, all cars should have been tested using the radar arrangement, which would have included retests for the teams already tested using the fifth wheel. However, there just wasn't enough time, due in large part to the two days of rain during the pre-race week.

Each method had its own peculiar, potential sources of error. There was some doubt expressed about the accuracy of the fifth wheel because it was suspected of bouncing off of the pavement during some runs. With the radar setup the reaction times of the driver and timers were introduced into the acceleration tests. These are different kinds of errors, and there is no really effective way to reconcile them. The errors, however, were estimated to be small compared to the quantities being measured.

An overall evaluation of performance testing might be summed up in one sentence: It was fair to the entrants as competitive teams, but unfair to the vehicles in that it did not provide enough data to give a good comparison to standards which have been established using typical production cars. The one exception to the above would be the use of the two different speed measuring setups. Except for that unfortunate circumstance, every team had an equal, though limited, opportunity to prove their vehicle. Driver errors, skill, and luck all played a part, but we would hope that adequate time and facilities could be respectively allotted and secured in future events.

PERFORMANCE TEST DATA

Presented on the following page in Table IV - 1 are the measurement values and scores recorded by the organization committee for the CACR entrant teams during the vehicle performance testing.

Note that the maximum number of points which any entrant team could have obtained was 1000 as can be seen from the following formula:

$$P = P_a + P_{a_d} + P_{udc} + P_n$$

where each of the individual tests described earlier in this chapter had a range of 0 to 250 points on the scoring curves.

FUEL ECONOMY MEASUREMENT - INTRODUCTION

Fuel consumption is an important design and operating parameter in any automotive power plant. Since the demonstration of reasonable fuel economy had from the beginning been one of the goals of the CACR competition, it was decided by the entrant teams and the organization committee in joint session that the fuel economy measurement should be comparable in importance to the performance tests and race score, and therefore have a maximum obtainable value of 1000 points.

Table IV - 1

CACR Vehicle Performance Scores

Entrant Team No.	Hanscom Field Test Scores: P =	P_a +	P_{a_d} +	P_{udc} +	P_n	Fuel Economy: Measurement miles/10^6Btu	Score
1	397	24	0	231	142	146.0	663
2	563	81	86	246	150	104.0	402
3	410	29	14	250	117	228.0	1000
4	543	30	113	250	150	171.5	822
5	539	29	120	215	175	169.0	806
6	391	24	0	225	142	107.0	419
10	583	24	134	250	175	205.0	1000
11	588	79	101	250	158	224.0	1000
12	559	75	112	222	150	114.2	464
15	763	224	147	250	142	127.0	544
16	434	107	34	118	175	104.4	402
17	475	26	58	233	158	162.5	766
18	698	135	171	250	142	111.2	445
19	647	55	250	250	92	254.0	1000
20	715	54	238	248	175	136.2	601
21	656	124	115	250	167	147.2	670
22	543	46	97	250	150	269.0	1000
23	504	119	0	218	167	132.3	577
24	664	186	86	250	142	161.0	756
30	629	59	188	232	150	99.8	374
31	607	170	70	250	117	142.1	638
32	630	97	125	250	158	175.2	845
33	527	8	102	250	167	128.5	553
34	486	22	72	250	142	228.0	1000
35	562	139	56	250	117	126.4	540
36	792	250	125	250	167	196.3	977
37	653	87	158	250	158	288.0	1000
41	568	57	93	235	183	171.0	819
42	329	0	0	187	142	360.0	1000
50	359	26	0	183	150	98.7	367
51	608	164	44	250	150	165.0	781
52	441	45	0	238	158	216.0	1000
61	88	0	0	88	-	-	-
65	378	0	0	195	183	-	936
66	397	0	41	156	200	-	665
70	133	0	0	0	133	-	-
71	292	0	0	92	200	147.6	672
75	473	46	60	250	117	143.8	649
90	65	0	0	48	17	24.0	0

A (-) indicates that the vehicle did not complete that portion of the competition.

TEST DESCRIPTION

To establish a sufficiently accurate baseline for the test vehicle fuel, consumption was measured over two legs of the race from Ann Arbor to Oklahoma City -- a distance of 1071 miles. It should be noted that this consisted of practically continuous high speed (60 to 70 mph) on interstate highways.

Because many different fuels were used by the various entrant teams, fuel consumption was computed in units of vehicle miles traveled per million British thermal units of energy consumed (miles/10^6 Btu). No allowance was made for vehicle weight or drag. The reasons for this decision were as follows:

1. With the exhaust emissions factor in the scoring formula expressed in units of grams/mile, a penalty for increased engine size already existed.

2. Vehicle weight would not be the dominant factor in determining fuel economy since the vehicles were being operated at high speed on interstate highways with few grades.

3. There was no straightforward method of allowing for the different vehicle drag coefficients.

The importance of aerodynamic drag at high speeds was underlined by the case of one entrant who illegally drafted in truck slipstreams for a substantial fraction of the route. The driver improved his vehicle's economy performance by about 25 percent. (He was, of course, penalized for dangerous and illegal driving).

MEASUREMENT METHOD

With the exception of the pure electric vehicles, the fuel economy measurement in units of miles/10^6 Btu was computed by recording the weight of the fuel consumed over the 1071-mile route for each entrant team. In a few cases, a shorter distance of vehicle travel had to be used due to inadequate fuel consumption records. The higher heating value of each fuel type (see Table IV - 2) was then used to give the energy consumption.

Table IV - 2

Higher heating values of the fuel types used in the CACR.

Compressed natural gas (CNG)	1,070	Btu/standard cubic foot (scf)
Liquefied natural gas (LNG)	1,034	Btu/scf
Liquefied propane gas (LPG)	91,500	Btu/gal
Diesel Fuel	143,000	Btu/gal
Gasoline	116,000	Btu/gal
Kerosene, JP-4	130,000	Btu/gal
Methanol	64,600	Btu/gal

The scoring curve is shown in Figure IV - 6 below; the breaking points of 40 and 200 miles/10^6 Btu correspond approximately to 5 and 25 miles/gallon for gasoline.

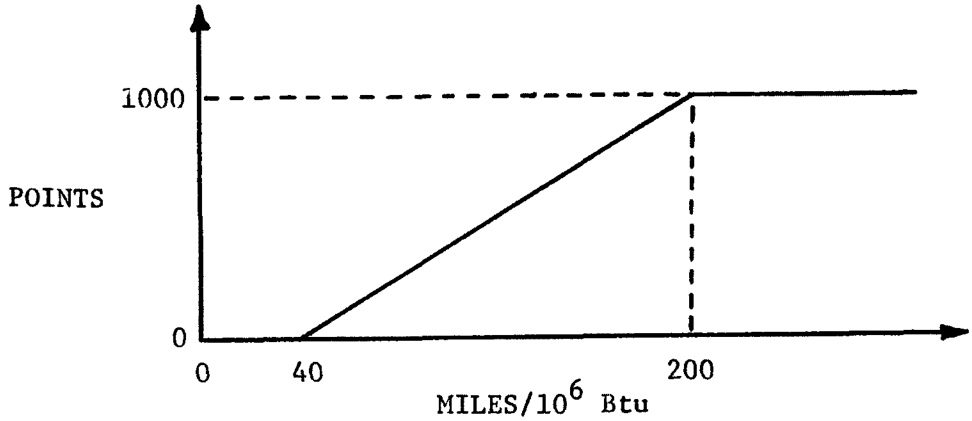


Figure IV - 6: Scoring curve used for the fuel economy measurement test.

Entrants were not required to provide accurate fuel meters in their vehicles. This led to some difficulties in monitoring the fuel consumed, and in future events such a requirement to provide against this should be made. The measurement methods used for the different fuels have been outlined in Table IV - 3.

Table IV - 3

Fuel	Fuel Consumption Measurement Methods
leaded gas diesel	Read gallons off pump*
unleaded gas alcohol kerosene	Cans of fuel weighed at impounds*
LPG	Record gallons fed to tank from meter reading on the pump*+
LNG	Standard flowmeters recording volume flow in scf
CNG	Record gas pressure and temperature in cylinder before and after each filling

* A full fuel tank was taken as the reference mark.

\+ This was the least accurate measurement because (1) it was difficult to assess when the tank is full; (2) flow meters at propane filling stations were not always reliable.

RESULTS

Petroleum Fueled Vehicles

Fuel consumption measurements in units of miles/10^6 Btu and fuel economy points scored by all entrants burning petroleum fuels have been listed in Table IV - 1.

Pure Electric Vehicles

It was not possible to measure the electrical energy used at all charging stations by the electric entries. The energy consumption of the two pure electric vehicles (No. 65, Cornell University, and No. 66, Stevens Institute of Technology) which reached Pasadena was measured over a special 150 mile route at the end of the race. Batteries, initially fully charged, were recharged three times over during this test run, and the energy consumption in units of kilowatt-hours recorded.

A fuel economy measurement was then computed in units of miles/kwh. To make these figures directly comparable to petroleum fueled vehicles, it was assumed that the electric energy available at the charging station was generated from fossil fuel at 35 percent efficiency. The electric energy consumption (miles/kwh), and thermal energy consumption (miles/10^6 Btu) test scores for entrant teams 65 and 66 are given in Table IV - 4.

Table IV - 4

Electric Vehicle Energy Consumption

Entrant No.	Electrical Miles/kwh	Thermal* Miles/10^6 Btu	Point Score
65 Cornell	1.85	190	936
66 Stevens	1.43	146.5	665

* Assumes 35% efficiency in the electrical power generation process.

EVALUATION

The fuel economy results span the range 100-270 miles/10^6 Btu which is equivalent to 13-34 miles per gallon of gasoline. The performance of race vehicles was therefore comparable to current automobiles. One question explored was whether the different fuels used by entrant teams had a measurable effect on fuel economy. Figure IV-7 shows fuel economy plotted against engine displacement. A rough correlation exists, but within the scatter of the data there are no discemable differences between the various fuels used.

It is interesting to note that the thermal efficiencies of the two electric entries when expressed in miles/10^6 Btu of thermal energy fed to the utilities electrical power generating plant, fall in the middle of the range of values measured for the petroleum fueled vehicles.

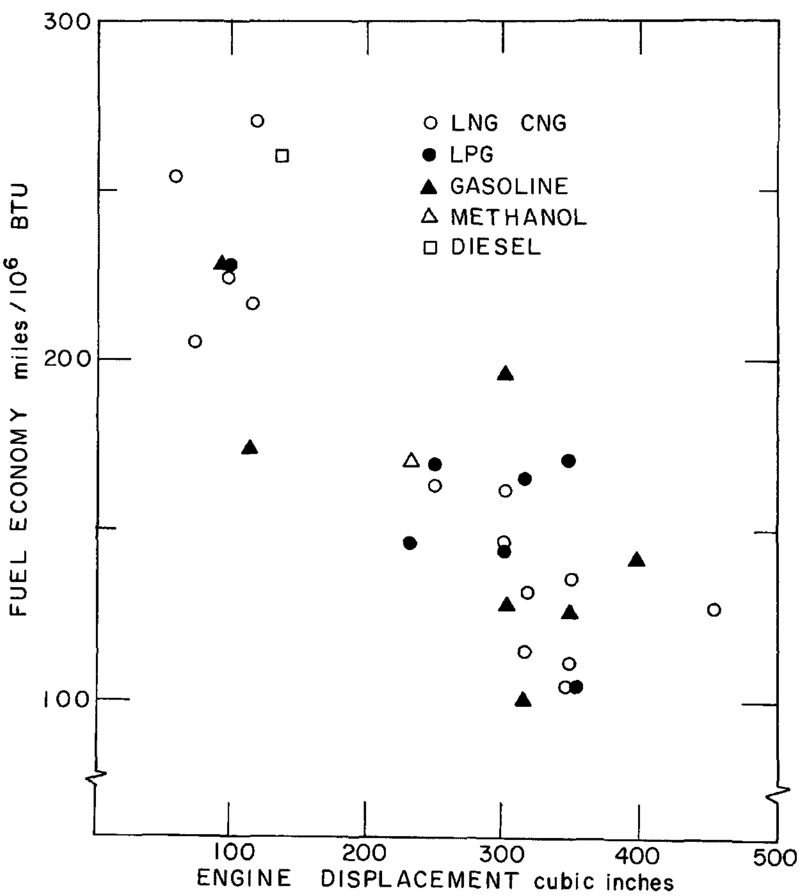


Fig. IV-7: Fuel economy vs. engine displacement

V

V. EXHAUST EMISSION STANDARDS AND CACR TEST PROCEDURES

INTRODUCTION

The proposal to stage a Clean Air Car Race (CACR) encompassed the idea of reducing exhaust emissions for any type of vehicle power plant to levels well below that of the present internal combustion engine (ICE). Acceptable standards for entrant team qualification and the test procedures for measuring vehicle tailpipe pollution and assessing vehicle performance characteristics had to be determined in order to establish the guidelines of greatest importance to all CACR participants.

The difficulty of this task was reflected by the extensive overhaul which the current Federal test procedure for measuring vehicle exhaust emissions has recently received. One need only inspect the Federal Register (Volume 33, Number 108, June 4, 1968; Volume 35, Number 186, July 15, 1970) to discover the modifications which have been made over the past two year period. No longer will the concentrations of exhaust volume pollutants be the object of measurement, but, more important, the actual mass values for these respective pollutants in units of grams per mile of vehicle travel will instead be recorded. Because the newly proposed Federal test procedure for 1972 required measurement equipment which could not be readily obtained at all CACR test sites, the organization committee in conjunction with engineers from General Motors, the Ford Motor Co., and the National Air Pollution Control Administration formulated test procedures which combined approved measurement techniques with available hardware.

Inherent difficulties in designing a standard test procedure to measure exhaust emissions for all vehicles became manifest when consideration was given to the operating characteristics of the unconventional automotive power plants. Turbines, for example, possess extremely high mass flow rates (1.0 to 2.0 lb-m/sec) compared to an ICE. Hybrid-electrics did not have their charging engines running throughout the duration of the emissions test. In short, proposing a test procedure for non-ICE power plants became necessary because no commonly prescribed procedure had ever been established at that time.

Even before the methods of testing for vehicle exhaust emissions had been investigated, the organization committee had proposed that all entrants comply with the then-proposed Federal standards for 1975 as a necessary requirement for participation in the CACR. Little did we understand or appreciate the complexity of this issue as we were not well-read or at all experienced with the far-reaching modifications that had been made in the current test procedure. The following three sections outline how the organization committee handled the design of the CACR exhaust emission test procedures, how these test procedures were related to the existing Federal standards, and how the teams were scored for their emission control efforts.

SECTION A

EXHAUST EMISSIONS TEST PROCEDURES

Devising a method to test exhaust pollution emissions from an automobile is not altogether straight-forward. One important factor is the speed versus time schedule, i.e., the "driving cycle" over which the vehicle is operated during the test. Different driving cycle choices can easily alter final results by a factor of two, thereby making it difficult to compare test results from various driving cycles. How the pollutant sample is collected, what instrumentation is used to analyze the sample, and how the sample data is used to calculate actual emission values--all are factors which can effect the accuracy of a test and throw uncertainty into any comparison with data obtained via other tests.

The necessity for some degree of standardization led us to consider the existing 1970 and proposed 1972 Federal test procedures as desirable starting points. We utilized the methods employed in these procedures as much as possible by combining and modifying the different steps and techniques to construct a meaningful test while observing constraints of time avialability for testing, equipment availability, etc.

The remainder of this discussion will begin with a description of the 1970 and 1972 Federal test procedures, continue with a description of how these methods were modified for use in testing the CACR vehicles, and conclude with a general criticism of the modified test procedures.

In the 1970 Federal test procedure (henceforth referred to as 1970 FTP), the "seven mode" driving cycle is used and has been illustrated below.

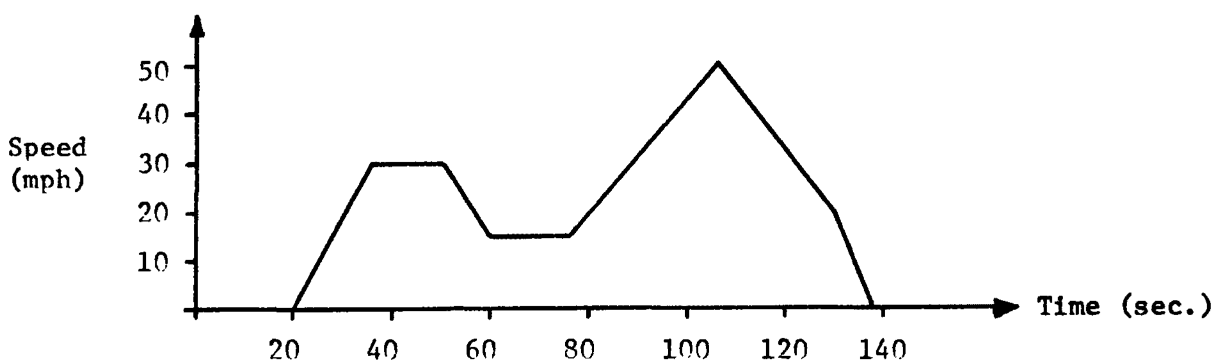


Fig. V - 1: Illustration of vehicle speed vs. time chart, commonly known as the "seven mode cycle", used in testing automobiles for exhaust emissions.

In preparation for the test, each vehicle is required to have its engine in an off-state for at least 12 hours (while parked in a temperature and humidity controlled room, if possible) before being pushed onto a chassis dynamometer and hooked to exhaust gas analyzing equipment. The chassis dynamometer is an instrument that simulates actual road-load conditions for the test vehicle; large rotational drums of variable incremental weight receive the torque-speed load applied by the vehicle's drive wheels, thereby allowing the vehicle to remain stationary while in operation (like running in place). A dynamometer inertia wheel is set so as to correlate with the energy absorption characteristics of the vehicle in travel. A device known as the power absorption unit is set to dissipate 4, 8, or 10 horsepower while the test vehicle is traveling at 50 mph; the setting is based upon the weight range to which the vehicle belongs. Seven repetitions of the seven mode cycle driving pattern are conducted to form the total test driving cycle and consume approximately twenty-one minutes in duration.

While the vehicle is being driven over the test cycle, a probe placed in the tail pipe continuously samples the vehicle's exhaust gases and routes a portion thereof through special gas analyzing equipment. In brief, the exhaust gas sample is piped through water vapor traps into a set of non-dispersive infared (NDIR) spectrometers which measure carbon monoxide (CO), carbon dioxide (CO_2) and hydrocarbons.

The test values from each mode are weighted by standard factors (to reflect that certain modes are more frequently encountered by the average motorist in an urban driving situation), corrected for differences in fuel composition and air-fuel ratio, and summed. Multiplication of this single number by the calculated, vehicle exhaust volume flow rate (determined by using a regression analysis which utilizes vehicle inertia weight) yields a value for the mass emissions per mile of vehicle travel for each pollutant.

For the 1972 and later model year cars, the Federal government will use a different test procedure (henceforth referred to as "1972 FTP"). The driving cycle for 1972 consumes almost 23 minutes of vehicle operation and exhibits a complex, non-repetitive speed vs. time behavior as illustrated below:

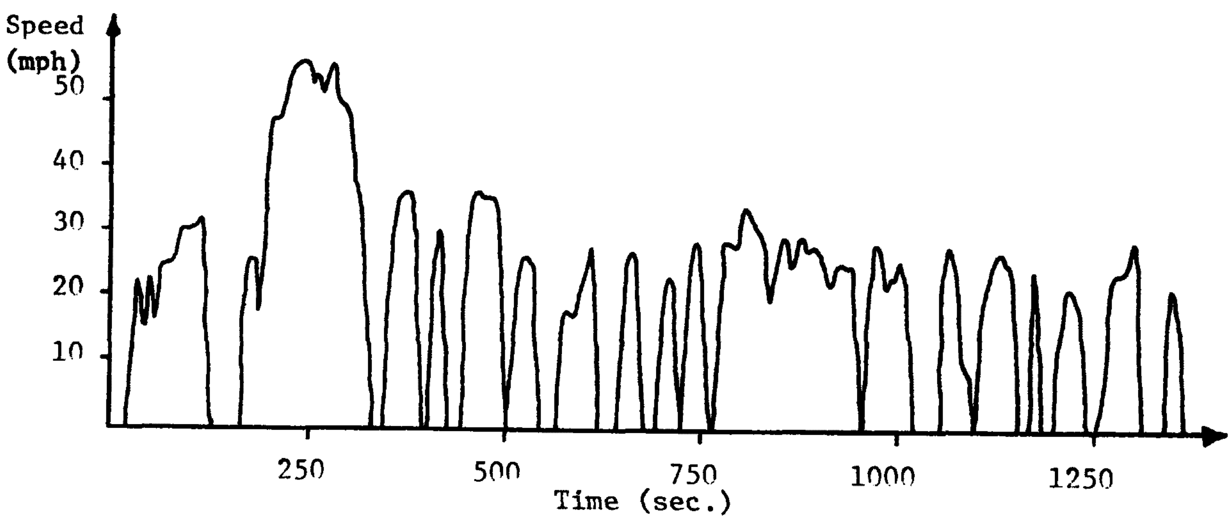


Fig V - 2: Illustration of the vehicle driving cycle for the 1972 Federal Test Procedure.

Throughout the cycle, a technique known as constant volume sampling (CVS) is employed. All of the test vehicle exhaust gas is collected, combined with filtered air to form a constant volume flow rate of dilute mixture, and temperature stabilized through a heat exchanger. A portion of this dilute mixture is then sampled at a low, constant volume flow rate into a large, transparent, plastic bag. The bag sample is analyzed using an NDIR spectrometer for CO and a flame ionization detector (FID) for hydrocarbons. The number of revolutions of the pump in the CVS unit are counted and used to calculate the total volume of the mix. By conducting concentration measurements (with this volume which is temperature and pressure corrected) of the different pollutants in the bag to determine the respective densities, this information can be combined with the CVS pump measurement and the total distance traveled by the vehicle during the driving cycle to give the mass of emissions for each pollutant per mile of vehicle travel.

Exhaust emissions testing of all CACR vehicles was conducted on three separate occasions during the competition: (1) in Cambridge, during pre-race activity, using the Ford Mobile Emissions Laboratory; (2) in Detroit, 1000 miles into the Race at the laboratories of the Ford Motor Co., General Motors Corp., Ethyl Corp., Chrysler Corp., and NAPCA; and (3) in Pasadena, at the conclusion of the race using the California Air Resources Board (CARB) and Olsen Mobile Test Laboratories (with instrumentation and additional assistance of personnel from the Scott Laboratory).

For the Cambridge and Pasadena testing, CVS equipment was not available. The test method used was identical to the 1970 FTP except:

1. Vehicles were tested from a "hot start", i.e., there was no pre-test engine-off period;
2. Readings from the sixth and seventh repetitions only of the seven mode cycle were used in the data reduction process;
3. Hydrocarbons were measured using an FID;
4. Nitric Oxide (NO) formation was measured with an NDIR. The NO data was weighted and corrected in the same manner as was done for CO and hydrocarbons, but with the addition of a correction factor for ambient humidity; and,
5. Particulate matter in the exhaust gas was measured by sampling a controlled constant volume flow rate through a heated glass filter. The readings were corrected using a calibration curve established by a different procedure for the measurement of particulates.

Although CVS equipment was available in Detroit, time constraints prevented the use of the 1972 FTP. The test procedure used resembled the 1970 FTP except as detailed below:

1. The pre-test engine-off period (known as the "cold soak" period) was only four hours instead of the prescribed 12 hours or longer;
2. FIDs were used to measure hydrocarbons;
3. Total nitrogen oxides formation (written symbolically as NO_x or NOX) was measured using NDIR and nondispersive ultraviolet

(NDUV) spectrometers except at NAPCA facilities where the Saltzman technique (a wet chemical method) was used;

4. Nine repetitions of the seven mode cycle were conducted instead of the prescribed seven;
5. On all entrant vehicles except numbers 42, 71, and 90, CVS equipment and CVS data reduction were used;
6. On those entries listed in (5), an equivalent fuel-based system technique was used, in which vehicle exhaust volume in each mode is calculated from a measurement of fuel consumption in that mode, coupled with measurements of CO, CO_2, hydrocarbons, and exhaust gas temperature.

Due to the variances from standard test procedures used in testing the CACR vehicles, care must be taken in comparing CACR data with other existing data obtained via the 1970 FTP or the 1972 FTP. There is also some question as to how well results from different test laboratories correlate, even when the instruments have been calibrated from the same gas sample.

PROBLEMS IN OBTAINING ACCURATE MEASUREMENTS

In general in emissions testing, considerable effort is expended to ensure that results from different test cells are accurate and reproducible. However, when analyzing the exhaust emissions data obtained with the test procedure outlined in this section, several possible sources of error must be considered and evaluated. The problems encountered during CACR testing fall roughly into those categories: procedural differences between tests, driver performance, and measurement system inaccuracies.

CACR test methods introduced some special procedural difficulties. The Detroit cold-soak time for CACR vehicles was set at a maximum of four hours. Some teams waited longer before their tests, which may have had a slight effect on the subsequent warm-up time of their catalytic and thermal reactor systems. Some CACR entrant vehicles overheated during emissions tests. Whether this was due to variability in fan cooling capacity or fan placement, or due to inadequate control of engine coolant temperatures by the entrant team was not ascertained.

The chassis dynamometer contains a power absorption unit as explained earlier in this section, which is adjusted to road load at 50 mph vehicle speed and set on the basis of vehicle weight. There is some question whether this technique adequately represents road-load conditions for the wide range of vehicle models (and vehicle weights) entered in the CACR.

In CACR emissions tests in Detroit, professional drivers were used to ensure the rapid testing of vehicles. Questions were raised by some entrants about driver performance, gear-shift timing, and engine stall during their tests. Since driving procedures are carefully standarized, it was felt that the slight variations in driving procedure during the cycle would have a minor effect on emissions. The effect of an engine stall during a cold start is more complicated. The Federal Test Procedure clearly spells out that the engine be restarted and the test continue. Some CACR entrants were given the option of a retest; in other cases, due to time limitations, entrants were not given this option. While a stall can effect the vehicle exhaust emissions, it was not clear whether the stalls which occurred resulted from poor engine drivability (and which should therefore remain in the test), or from the driver's lack of familiarity with the vehicle.

Since most CACR entrant vehicle emissions were substantially below those of current automobiles, the question of the accuracy of current instrumentation was carefully considered when test procedures were being developed. Cutoff levels, below which measurements were considered questionable, were introduced for HC, CO, and NO_x concentrations. The values used in hot and cold start tests are given in Section C. Emissions below these levels were assigned the cutoff values in the scoring formula.

Also, because emissions were low, the concentrations of pollutants in the ambient air used to dilute the engine exhaust in the CVS sampling system become important. This diluting air is sampled just downstream of the filter in the CVS system, collected in a bag and analyzed, and these pollutant concentrations subtracted from the corresponding concentrations in the exhaust sample bag. Errors are introduced because no correction is made for the vehicle exhaust gas volume which is about 10 per cent of the flow through the constant volume displacement pump. This error is negligible if the pollutant concentrations in the air sample bag are small compared with the exhaust bag. However, for some CACR entrants the two sets of concentrations were comparable in magnitude. Under these circumstances, the error would vary with engine size with their different exhaust gas flow rates. These problems underline the need for clean diluent air. Also, had a turbine with its much larger exhaust gas volume been tested on a CVS system, the error introduced would be more significant and corrections would have to be made.

In general, it was concluded by the engineers who established the test procedures that the errors normally encountered in testing vehicles was within about 10 per cent for any given vehicle.

SECTION B

THE FEDERAL EXHAUST EMISSION CONTROL STANDARDS

In Table V - 1, the Federal timetable for reducing vehicle exhaust emissions has been illustrated as it existed at race time in the summer of 1970. These standards had been formulated in November of 1969 by the National Air Pollution Control Administration (NAPCA), an agency within the U.S. Department of Health Education and Welfare at that time. The Air Quality Act, passed by Congress in 1967, had invested within NAPCA the authority to investigate the issue of vehicular emissions and subsequently promulgate abatement standards.

Throughout 1969, a new test procedure, which employed what is called "constant volume sampling" (CVS) equipment to collect vehicle exhaust gas, was undergoing research and development. Its feasibility as an advanced test procedure had been established, but the correlation of its pollutant measurement values to those obtained using the customary continuous sampling technique had yet to be determined. Over the course of time, testing programs using both measurement procedures revealed that the CVS hardware yielded pollutant emission values in vehicle exhaust gas that were significantly higher than those obtained using the continuous sampling technique. For example, referring to Table V - 1, the corresponding emission values obtained using the 1970 Federal Test Procedure (see Section A of this chapter) when testing an uncontrolled vehicle are 73.0 gm/mile for CO and 11.2 gm/mile for HC (in comparison to the figures of 125.0 and 16.8 measured respectively using the 1972 FTP). For a vehicle whose exhaust pollutant levels meet the 1970 standards listed in Table V - 1 using the 1972 FTP, the 1970 FTP records corresponding values of 23.0 gm/mile for CO and 2.2 gm/mile for HC. As can be seen from the data presented, the 1970 FTP fails to catch approximately half of the vehicle exhaust pollutants by weight.

Realizing the discrepency between measurement procedures, the CACR organization committee opted to employ CVS to obtain the desired measurement accuracy, but the limited availability of this type of hardware compelled the committee to accept the compromise discussed in Section A of this chapter. Although entrance qualifications had required that all CACR entrants meet the then-proposed 1975 Federal Standards, the question of test procedures to be employed in making the measurements was not fully understood in the early days of committee existence. As can be seen from Table V - 1, requiring the entrants to meet the then-proposed '75 standards using CVS equipment was asking for a great deal.

A second major modification recently made to the 1970 FTP, which has been included in the 1972 FTP, was the substitution of a newly formulated driving cycle (commonly referred to as the LA-4) as illustrated in Figure V - 2. Once again, the pollutant emission values obtained using this particular driving cycle were higher than what had formerly been obtained using the standard seven mode cycle. Investigation into differences in emission measurement values resulting from these two different driving cycles is still underway at present with no conclusive correlation between government and industry test programs having been reached as of yet.

The combination of CVS hardware and the non-repetitive driving cycle illustrated in Figure V - 2 constitute the major elements of the proposed 1972 FTP. Other detailed modifications of lesser importance have also been made in revising the 1970 FTP; these are not essential for purposes of providing the reader with additional significant information.

The recent Amendments to the Clean Air Act which were passed by Congress last December has accelerated the exhaust emission reduction schedule. By model year 1975, the auto manufacturers will be required to attain levels of 0.45 gm/mile and 4.7 gm/mile for HC and CO respectively using the 1972 FTP. In 1973, there will very likely be an NO_x control requirement of 3.0 gm/mile which may well be reduced to 0.4 gm/mile for model year 1976 autos.

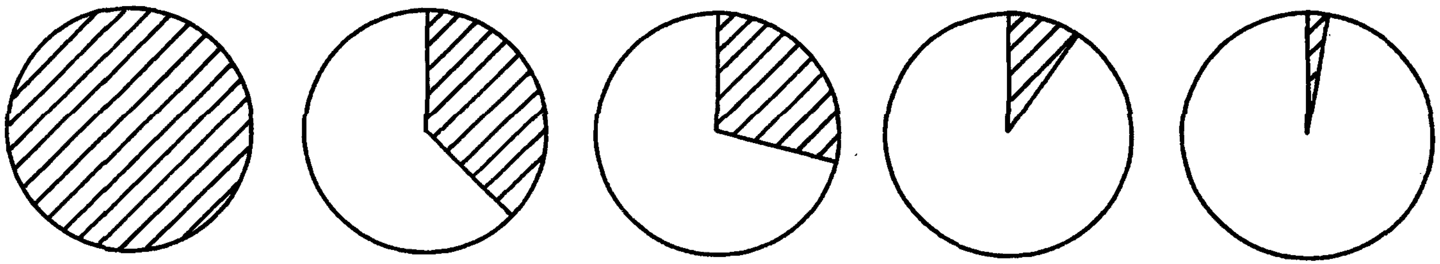
There can be little doubt that the percentage of emission reduction achieved over an uncontrolled automobile will have exceeded 90% by 1976 if the auto manufacturers meet the proposed standards. In retrospect, it would seem that the CACR entrants had indeed placed themselves on the frontier of exhaust emission control technology.

<u>Table V - 1</u>

Federal Emission Standards

(Based on proposed 1972 Federal test cycle procedure)

	BASELINE	ACTUAL - 1970	PROPOSED - 1972	PROPOSED - 1975	PROPOSED - 1980
CO					



Grams/mile:	125.0	47.0	39.0	11.0	4.7
Reduction from baseline:		62%	69%	89%	96%
HC					

Grams/mile:	16.8	4.6	3.4	0.5	0.25
Reduction from baseline:		73%	80%	97%	98.5%
NO_x					

Grams/mile:	6.0	6.0	6.0	0.9	0.45
Reduction from baseline:		-	-	85%	93%
PARTICULATES					

Grams/mile:	0.3	0.3	0.3	0.1	0.03
Reduction from baseline:		-	-	67%	90%

SECTION C

THE CACR EXHAUST EMISSIONS SCORING FORMULA

The reduction of exhaust emissions was originally conceived as the most important facet of the CACR competition. In order to maintain emphasis along these lines, a nonlinear scoring formula was desired which would award an entrant team with an increasing-return-to-scale point system. With a linear formula, a reduction in emissions beyond the 1975 Federal standards of, for example, 50% for HC, CO, and NO would give that particular team an emissions score that was 50% higher than a team which simply met the standards. The reward in all cases then would be directly proportional to the improvement achieved in bettering the 1975 Federal standards. A nonlinear formula, on the other hand, would reward the team more heavily for the same degree of emission reduction. An inversely proportional scoring system, for example, would double an entrant team's score in the case where it had reduced all pollutants by 50% beyond the 1975 Federal standards.

The three major automotive pollutants, - HC, CO, and NO_x - had to be considered in devising a suitable formula, and a basis had to be found whereby their individual levels of magnitude as measured within the vehicle's exhaust gas would weigh separately when plugged into the scoring formula. The possibility that the pollution control devices on some of the CACR vehicles might degrade in performance over time made it desirable to conduct a measurement for deterioration. The use of two different test procedures for the exhaust emission measurements required that the two sets of data obtained on each vehicle be used in separate ways. It was within this framework of constraints that a complicated, nonlinear scoring formula for emissions evolved.

The basic nonlinear structure of the formula for 'E', the emissions factor, expressed in units of absolute points, has been illustrated below:

$$E = \frac{1}{\frac{1}{3}\left[\frac{E_{CO}}{11.0} + \frac{E_{HC}}{0.5} + \frac{E_{NO_x}}{0.9}\right]} + \text{PART}$$

where E_{CO} = the Detroit cold start test measurement value for carbon monoxide.

E_{HC} = for hydrocarbons.

E_{NO_x} = for oxides of nitrogen.

PART = a value derived from a measurement for particulate matter in the vehicle exhaust.

The numbers 11.0, 0.5, and 0.9 are the respective levels in grams per mile for CO, HC, and NO_x which, at the time of the race, constituted the then-proposed 1975 Federal standards. These values became, in effect, the weighting factors which determined each pollutant's influence upon the total score.

PART, a value obtained from particulate test measurements conducted in Cambridge and Pasadena, constituted a separate term in the exhaust emissions scoring formula. The two measurements were averaged together and PART received one of the following three values: −0.1, 0.1, or 0.2, depending upon whether the average value of the measurements was greater than 0.1 gm/mile, between 0.1 and 0.03 gm/mile, or less than 0.03 gm/mile respectively. 0.1 gm/mile constituted the then-proposed 1975 Federal standard for particulate emission control, and .03 gm/mile the then-proposed 1980 Federal standard.

To assess the amount of deterioration which each vehicle's emission control system experienced during cross-country travel, a deterioration factor was computed separately for CO, HC, and NO_x. The factor in each case consisted of the measured value of the specific pollutant in Pasadena, divided by the value obtained in Cambridge. If the ratio turned out to be less than 1, i.e., the vehicle's emission control system theoretically improved itself during cross-country travel, a deterioration factor equal to 1.0 was assigned. The mass emissions measurement obtained during the Detroit testing for each pollutant was then multiplated by the appropriate deterioration factor.

Although pollution emission control of the exhaust gases is one of the most important problems of present day cars, a point is ultimately reached where levels become so low that other considerations concerning vehicle operation begin to dominate in importance. The proposed 1980 Federal standards at race time (which Congress has now put into effect in a somewhat modified form to apply to the 1975 and 1976 model year automobiles) were designed to be sufficiently low and thereby cause atmospheric CO, NO_x, and oxidant levels to drop to an acceptable state commensurate with reasonable air quality standards. For a CACR vehicle achieving the 1980 standards, the E factor in the scoring formula already more than doubled in value. Since its value continues to rise much more rapidly for emission levels any lower than this, the then-proposed 1980 Federal standards of 0.25 gm/mile for HC, 4.7 gm/mile for CO, and 0.4 gm/mile for NO_x were chosen by the committee as the lower cutoff values for scoring purposes on the Detroit cold start CVS data.

The above discussion of the deterioration factors, cutoff values, and overall scoring formula is summarized below in algebraic form.

Deterioration Factors

$$F_{CO} = \max \left[1, \frac{CO_{Pas}}{CO_{Cam}} \right]$$

$$F_{HC} = \max \left[1, \frac{HC_{Pas}}{HC_{Cam}} \right]$$

$$F_{NO} = \max \left[1, \frac{NO_{Pas}}{NO_{Cam}} \right]$$

Cutoff levels below which measurement readings were considered questionable during the hot start, continuous sampling testing are:

CO 0.1% HC 10 ppm NO_x 100 ppm

The measurement cutoffs for cold start CVS (Detroit) testing are:

CO 1.00 gm/mile HC 0.125 gm/mile NO_x 0.2 gm/mile

Detroit Testing Cutoff Levels [1]

$$E_{CO} = \max \ (4.7, CO_{CVS})$$

$$E_{HC} = \max \ (0.25, HC_{CVS})$$

$$E_{NO_x} = \max \ (0.4, NO_{x\,CVS})$$

Exhaust Emissions Factor

$$E = \frac{1}{\frac{1}{3}\left[F_{CO} \frac{E_{CO}}{11.0} + F_{HC} \frac{E_{HC}}{0.5} + F_{NO} \frac{E_{NO_x}}{0.9} \right]} + PART$$

Test Results

Presented in Table V - 2 on the following page are entrant team scores for the exhaust emission measurement tests conducted during the CACR. The emissions factor E appearing in the final column constitutes the value used to compute each entrant team's score using the formula described in Chapter III. The measurements obtained during the Detroit cold start CVS test have been listed in Table V - 2 along with the deterioration factors computed by the committee after hot start testing had been completed in Pasadena. Finally, the particulate emission measurement average value for each CACR vehicle has been recorded in the second column from the right.

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1. These are scoring cutoffs for Detroit tests, not the same as measurement cutoffs for Detroit tests given above.

Table V - 2

Exhaust Emission Test Measurements

Entrant Team No.	Detroit Cold Start Test Values (units of gm/mile)			Deterioration Factor			PART Test Values (gm/mi)	Emissions Score
	HC	CO	NO_x	$\frac{HC_P}{HC_B}$	$\frac{CO_P}{CO_B}$	$\frac{NO_P}{NO_B}$		
1	0.42	1.00	0.47	4.73	1.00	0.78	0.09	0.71
2	3.02	2.76	0.74	1.60	1.00	1.92	0.01	0.46
3	1.02	6.38	0.59	1.42	1.71	3.14	0.03	0.70
4	0.28	9.21	0.37	2.43	1.00	1.06	0.02	1.34
5	0.82	1.00	0.78	1.83	1.00	1.17	0.01	0.87
6	2.26	1.66	0.49	1.59	1.00	1.66	0.02	0.55
10	0.44	20.48	0.71	0.87	4.80	0.65	0.03	0.48
11	0.41	1.00	1.17	4.70	1.00	1.81	0.01	0.65
12	0.12	1.00	0.70	2.50	1.00	1.66	0.01	1.48
15	1.27	1.00	0.57	6.65	1.00	1.06	0.09	0.27
16	0.40	10.02	1.47	1.76	1.14	1.05	0.01	0.92
17	0.28	1.00	0.61	2.29	1.00	0.93	0.02	1.46
18	0.24	1.00	0.55	2.00	1.00	1.00	0.02	1.70
19	0.33	9.24	0.80	3.65	1.60	2.54	0.10	0.40
20	0.93	2.72	1.39	1.38	1.00	0.69	0.01	0.86
21	0.62	4.42	2.56	3.56	3.30	1.16	0.03	0.53
22	0.62	1.00	1.39	0.24	1.00	1.40	0.01	0.98
23	0.12	3.19	1.00	1.00	1.00	1.00	0.03	1.61
24	0.53	2.72	2.22	0.70	1.00	1.18	0.02	0.88
30	0.70	25.23	0.78	1.00	1.00	1.00	0.07	0.76
31	1.67	7.55	1.60	3.20	0.91	1.97	0.09	0.30
32	0.87	14.63	0.50	3.60	2.90	1.08	0.11	0.18
33	2.10	11.67	1.11	1.02	0.12	0.72	0.04	0.56
34	0.67	4.91	1.41	1.85	1.90	0.77	0.22	0.51
35	1.38	25.70	1.06	1.78	1.00	4.16	0.15	0.15
36	1.21	13.65	0.70	1.60	1.00	1.18	0.04	0.60
37	1.56	3.84	0.84	1.31	0.50	2.08	0.10	0.56
41	0.42	4.68	0.86	1.91	2.30	0.42	0.02	1.04
42	1.60	3.40	2.30	1.00	1.00	1.00	0.16	0.39
50	4.19	8.81	4.27	0.72	2.52	1.20	0.16	0.09
51	0.94	1.43	0.84	2.71	1.00	2.07	0.01	0.60
52	1.43	1.00	1.77	5.68	1.00	0.38	0.02	0.36
61	-	-	-	-	-	-	-	-
65	-	-	-	-	-	-	-	0.93
66	-	-	-	-	-	-	-	0.71
70	-	-	-	-	-	-	-	-
71	0.59	1.67	6.09	0.74	1.50	0.96	-	0.36
75	2.59	1.06	2.35	0.79	1.00	1.83	0.01	0.29
90	5.73	78.50	6.24	-	-	-	-	-

Table V - 3

Deterioration Factor Emissions Data

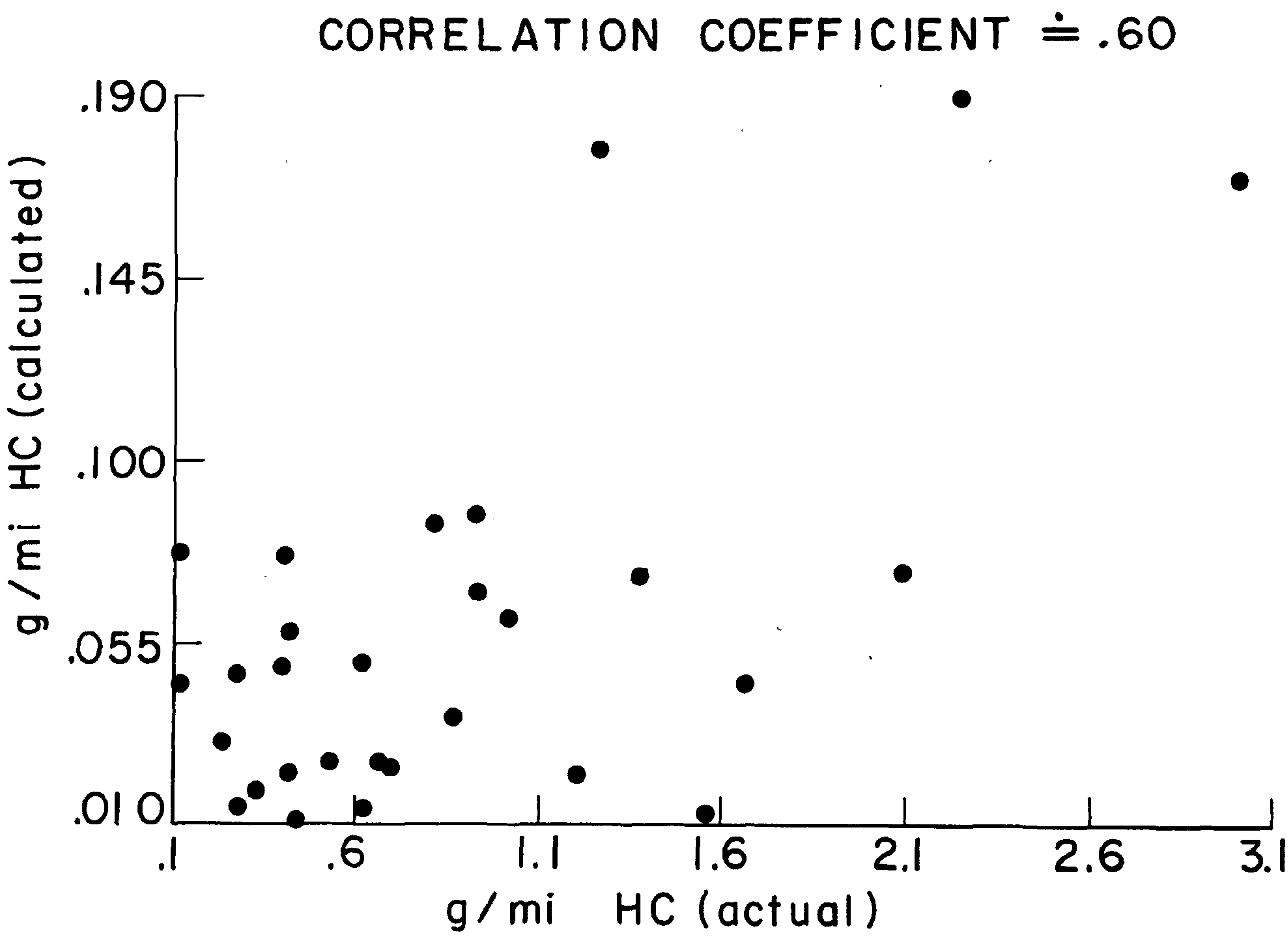
Entrant No.	CO (%) Cam.	CO (%) Pas.	HC (ppm*) Cam.	HC (ppm*) Pas.	NO (ppm*) Cam.	NO (ppm*) Pas.	Particulates (gm /mi.) Cam.	Particulates (gm /mi.) Pas.
1	.10	.10	11	52	128	100	.07	.12
2	.10	.10	40	64	100	192	.01	.01*
3	.21	.36	66	94	132	414	.05	.01
4	.10	.10	14	34	100	106	.02	.02
5	.10	.10	12	22	859	1004	.01	.01
6	.10	.10	82	130	100	166	.04	.01
10	.10	.48	23	20	155	100	.02	.04
11	.10	.10	10	47	260	471	.01	.01
12	.10	.10	10	25	108	179	.02	.01
15	.10	.10	17	113	155	165	.15	.03
16	.22	.25	21	37	289	314	.02	.01
17	.10	.10	24	55	165	154	.02	.02
18	.10	.10	10	20	100	100	.01	.03
19	.10	.16	20	73	428	1085	.19	.02
20	.10	.10	37	51	382	263	.01	.01
21	.10	.33	16	57	291	339	.05*	.01
22	.10	.10	369	87	470	657	.01	.02
23	.10	.10	24	37	301	299	.05	.01
24	.10	.10	61	43	288	340	.03	.01
30	1.35	-	13	-	100	-	.07	.07*
31	.11	.10	10	32	185	365	.13	.06
32	.10	.29	10	36	491	528	.05	.18
33	.06	.12	57	58	326	234	.04	.04
34	.10	.19	13	24	406	314	.30*	.15
35	.10	.10	27	48	233	970	.29	.02
36	.10	.10	10	16	100	118	.05	.04
37	.20	.10	13	17	190	396	.10	.10
41	.10	.23	23	44	279	116	.03	.02
42	.10	.10	141	66	472	480	.18	.15
50	.23	.58	337	243	1330	1590	.22	.10
51	.10	.10	28	76	168	347	.01	.01
52	.10	.10	128	727	780	294	.03	.01
71	.10	.15	27	20	1041	1000	-	-
75	.10	.10	58	46	336	615	.02	.01

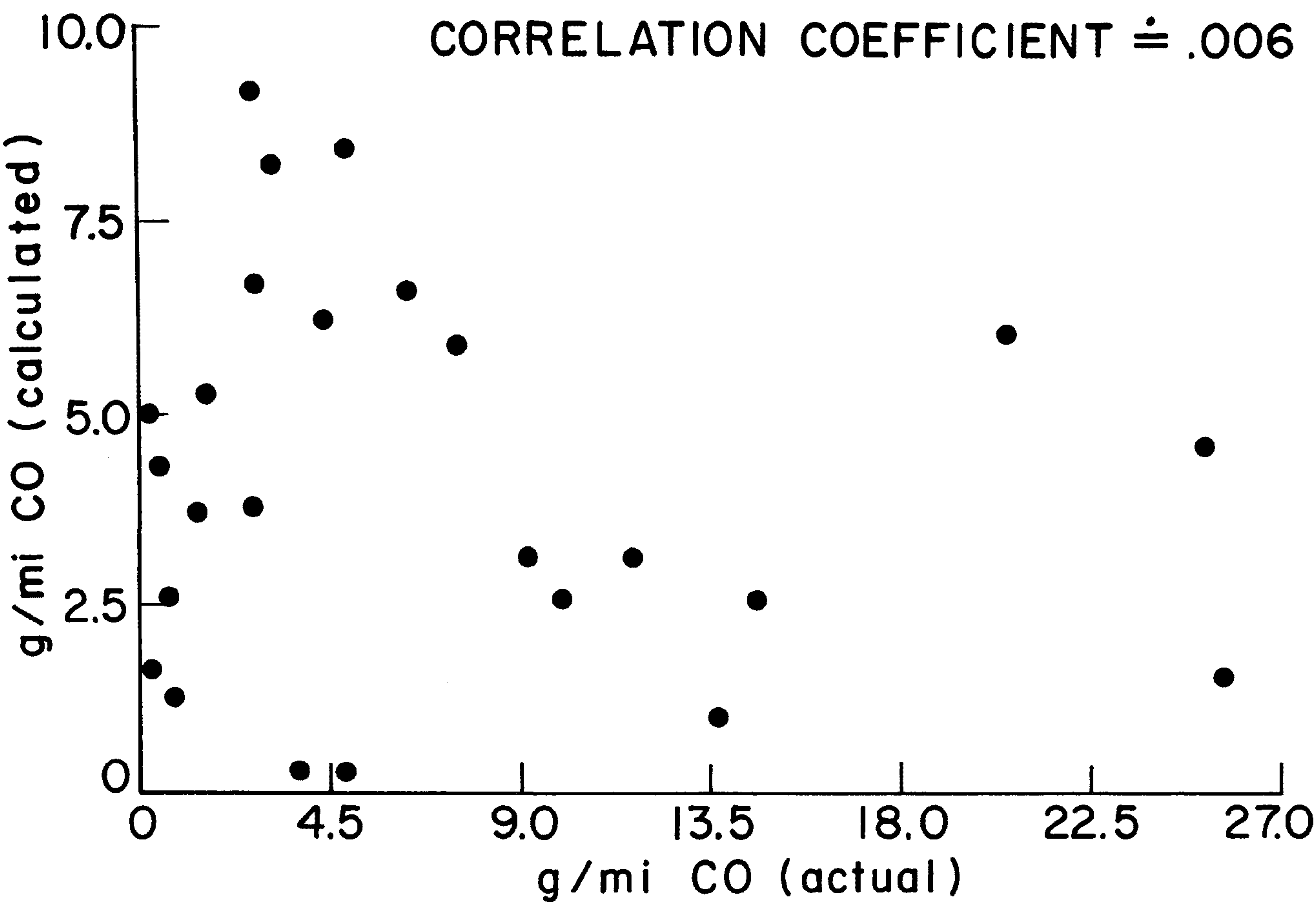
* ppm = parts per million.

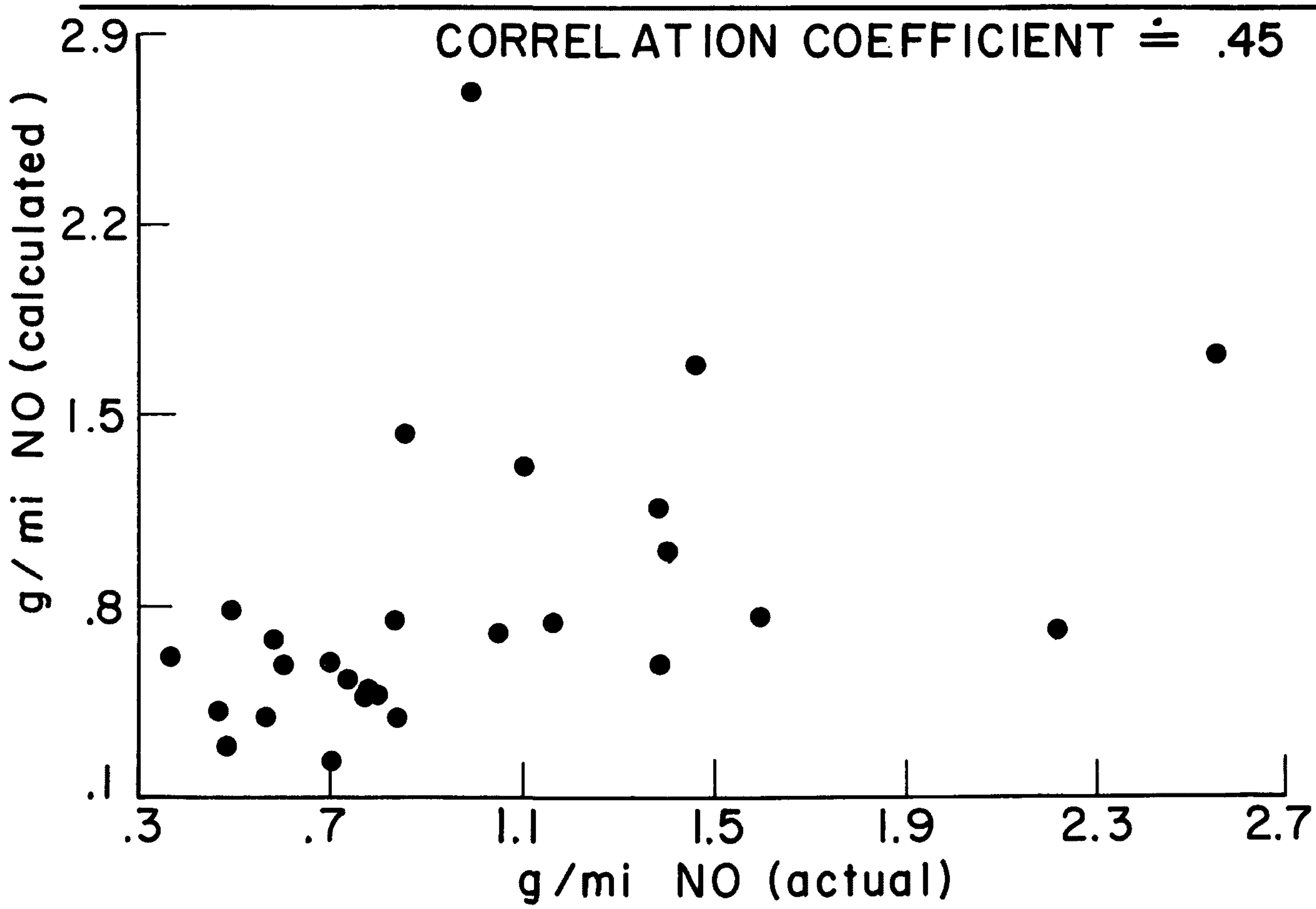
Correlation Between Test Methods

Equipment for performing 1970 FTP was available in Detroit, and so it was decided to continuously monitor exhaust gas concentrations during the Detroit testing, in order to gain some measure of the relations between the two methods used to test the CACR vehicles. The following three figures show the calculated emissions derived from continuous sampling in cycles six and seven versus the CVS results for the same vehicle during the total test for all ICE vehicles. The generally mediocre to poor correlations do not necessarily reflect upon the accuracy of the deterioration factor, since for any one vehicle the correlation may still be very good. However, doubts are cast upon the accuracy of using hot start continuous sampling values to estimate actual emissions of a range of different vehicles.

Fig. V-3




CORRELATION COEFFICIENT ≐ .006
10.0
7.5
5.0
2.5
0
g/mi CO (calculated)
0
4.5
9.0
13.5
18.0
22.5
27.0
g/mi CO (actual)


CORRELATION COEFFICIENT ≐ .45
2.9
2.2
1.5
.8
.1
g/mi NO (calculated)
.3
.7
1.1
1.5
1.9
2.3
2.7
g/mi NO (actual)

SECTION D

EMISSIONS RESULTS EVALUATION

In addition to fuel substitution, many emission control techniques and devices were used by CACR entrants to achieve low emissions. Almost all entrants ran their engines fuel-lean to obtain low HC and CO emissions; with gaseous fuels most teams ran sufficiently lean to reduce NO_x emissions. Nineteen entrants used catalytic afterburners to further reduce HC and CO. One entrant used a thermal reactor alone, and five used thermal and catalytic reactors in series. Twelve entrants used exhaust gas recirculation (EGR), and two water injection to reduce NO_x emissions; at least fourteen entrants retarded the spark timing to achieve lower NO_x values.

A wide variety of other techniques were used to more carefully control engine-operating conditions, e.g., control of intake air temperature, specially designed carburetors, insulated fuel lines, fuel injectors. Engine geometry changes were also made by some entrants, e.g., lower compression ratio, special piston rings to reduce quench volume, reduced valve overlap. The techniques employed and significant design changes are listed in detail in Appendix B, and summarized in Table V-4.

It had been hoped that the emission data obtained during the race would allow some evaluation of these various techniques. However, after a preliminary analysis of all the emissions data and control techniques used, no detailed evaluation was attempted. The reasons were the following:

1. Only limited emissions data were available on each vehicle, and for many vehicles emissions changed over the race route as evidenced by the deterioration factors significantly greater than unity in Table V-2.

2. Many different combinations of emission control techniques and devices were used on different types of engine and car (see Table V-4). Any cross comparison of emissions in an attempt to evaluate any particular control device would have doubtful validity.

3. The majority of entrant teams did not have adequate emissions-monitoring equipment available to them during the period they assembled their vehicles. The CACR emissions results do not, therefore, necessarily represent the optimum that can be achieved with the particular control devices used.

As an example of the difficulties involved in such cross comparisions, entrant teams 5, 15, and 19 used none of the standard control devices, e.g., catalytic or thermal reactors, exhaust gas recirculation, yet had emissions which were not significantly higher than other entrants in their class who did use some of these controls.

Some general conclusions can be drawn, however. Fuel substitution alone to natural gas or petroleum gas can give a substantial reduction

Table V-4: SUMMARY OF MAJOR EMISSION CONTROL TECHNIOUES

Entrant	Fuel	Vehicle Weight (lb.)	Engine Size (in^3)	EGR	Water Injection	Spark Retard	Catalytic Reactor	Thermal Reactor	NO_x Reactor
1	CNG	3840	232						
2	CNG	4750	351			x			
3	LNG	1825	98			x	x		
4	LNG	3800	350			x	x		
5	CNG	3800	250						
6	LNG	4350				x	x		
10	LPG	1942	73				x	x	
11	LPG	2438	98		x	x	x	x	
12	LPG	3980	318	x			x		
15	LPG	4200	454						
16	LPG	4011	350				x		
17	LPG	3300	250	x			x		
18	LPG	2960	350			x	x		
19	LPG	1900	58						
20	LPG	3100	351	x			x		
21	LPG	3434	302	x		x	x		
22	LPG	2109	116	x			x		
23	LPG	3610	318	x		x	x		
24	LPG	2597	302				x		
30	unl.gas	3700	318	x			x	x	
31	l.gas	4100	400	x				x	
32	unl.gas	2500	113			x	x	x	
33	l.gas	3000	302			x	x		
34	unl.gas	2500	98		x		x		
35	unl.gas	3800	350				x		x
36	ld.stl.gas	2300	302	x			x		x
37	unl.gas	1760		x		x	x	x	
41	alc.	2569	232	x			x		
42	diesel	2800	138						
50	alc/gas								
51	LNG	3500	318			x			
52	LPG	2300	115	x		x	x		

in emissions. By running their engines lean, entrant teams 5 and 15 achieved values in their Detroit cold-start test which only exceeded the then-proposed 1975 Federal Standards in hydrocarbon emissions. The Detroit test results also show that CO control was most easily achieved by lean engine operation and a catalytic afterburner. The average of all Detroit CO measurements was below the then-proposed 1975 Federal Standard; the average of HC and NO_x emissions increased for almost all entrant vehicles over the race route.

A comparision of the Detroit cold-start test data for different fuel types shows liquid-fueled entrants had about three times higher CO emissions and two times higher HC emissions than LPG fueled entrants. Average NO_x emissions for these two fuel types were quite similar. However, the Pasadena and Cambridge HC and CO data do not show this difference; emissions from liquid and gaseous-fueled vehicles are quite comparable. These data underline the more difficult cold-start emissions control problem for liquid-fueled vehicles, which must enrich the fuel/air mixture to compensate for poor fuel vaporization with a cold engine.

Particulate emissions also correlated roughly with liquid or gaseous fuel. Figure V-3 shows the particulate emissions data for each fuel type. Though there is considerable scatter, the mean value for gaseous fuels is about a factor of 3 below the mean of liquid fuels. Note that both leaded gasoline-fueled entrants used particulate traps to reduce their lead emissions.

In conclusion, the data obtained during the CACR confirm the already-known emissions reduction potential of many of the control devices and design changes used. It had already been shown[2] that fuel substitution to natural gas, and an engine tune-up, can achieve emission levels of HC--151 ppm (1.8 g/mile); CO--0.35 per cent (4 g/mile); NO_x--462 ppm (2 g/mile). CACR entrants, with a few exceptions, by using additional control devices considerably improved these emission values. The winner of the gaseous fuel class, No. 18-WPI, achieved values of HC--0.24 g/mile; CO less than 1 g/mile; NO_x--0.55 g/mile.

1970 model gasoline-fueled automobiles must meet Federal emission requirements of HC--2.2 g/mile; C)--23 g/mile; and NO_x emissions are about 6 g/mile.[1] The overall winner, No. 36-Wayne State University, in the retest requested by the CACR committee at Pasadena because operator error in the Detroit tests prevented those results from being a true measure of the vehicles's potential, achieved the following:[3]

HC 0.19 g/mile

CO 1.48 g/mile

NO_x 0.29 g/mile

2. California 7-mode cycle.

3. LA4, CVS test. Gives higher emissions than 7-mode test. See section V-B.

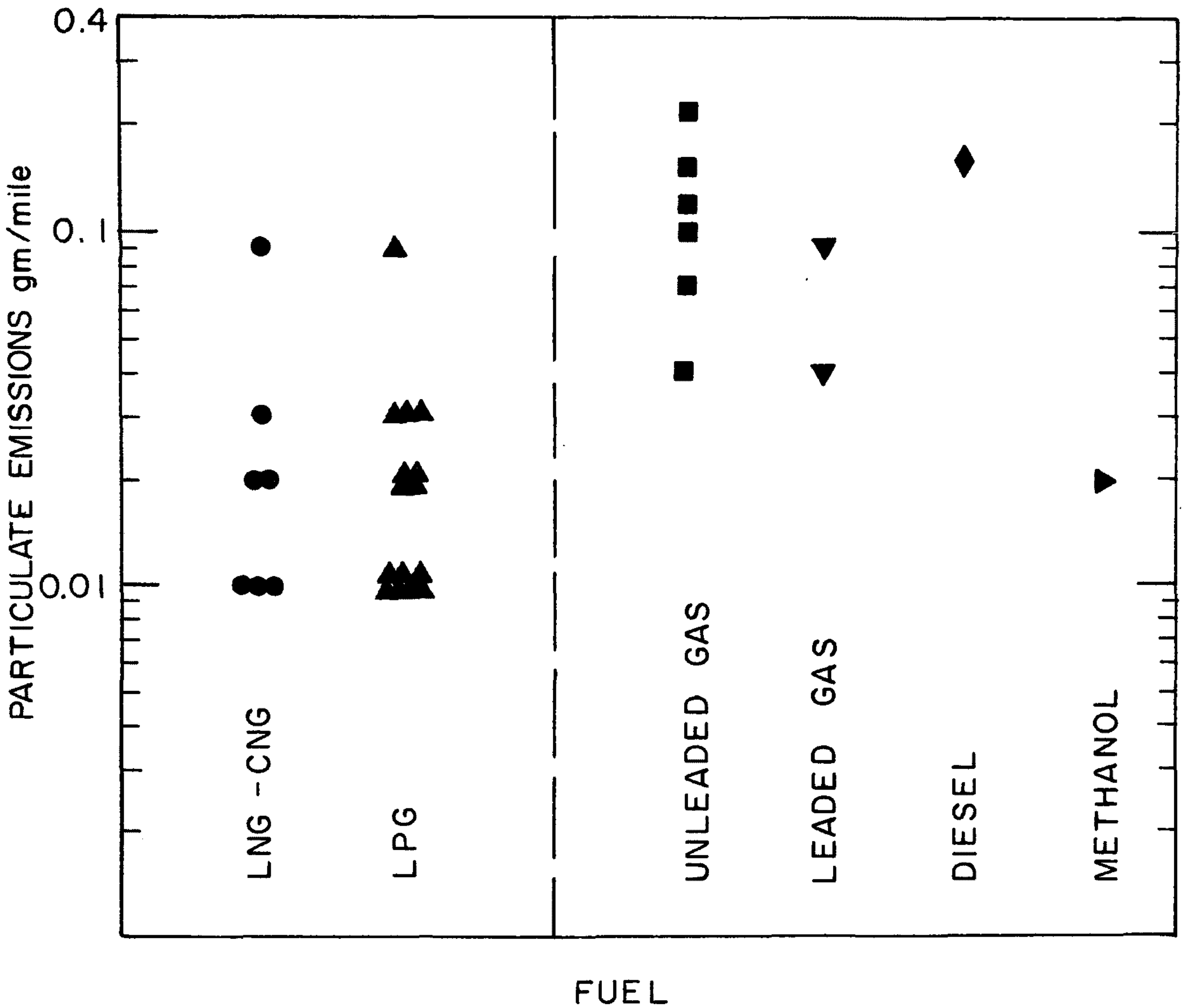


Fig. V-3: Particulate emissions by fuel type

The potential for emissions reduction through careful control of engine-operation conditions, through exhaust gas recirculation and catalytic reactors is readily apparent.

EMISSIONS ATTRIBUTABLE TO ELECTRIC VEHICLES

When discussing automotive emissions, it is often proposed that the electric vehicle is an especially attractive alternative in that is contributes no contaminates to the atmosphere during operation. This is true. However, electrical stored energy systems derive their power from electric generating plants and a case can be made that the consumption of fossil fuel by these facilities produce pollution which in turn can be attributable to electric vehicle operation.

In introducing an investigation of the magnitude of this pollution, it will be assumed that electric vehicles travel 1.6 miles per kilo-watt hour consumed[4]. In allowing for power station efficiency, the thermal energy required for this is 164 miles per million Btu.

If coal is used as a plant fuel, a conservative assumption is that it is 10% ash and contains 2% sulphur. Its heating value is 26 x 10^6 Btu/ton. Using a recognized source[5], the amount of pollution emitted by the electrical generating plant in producing power for electric vehicle consumption may be expressed in grams per mile as follows:

CO	HC	NO_x	SO_2	Particulate
.05	.02	2	8	0.3

By investigation, it is noted that although CO and HC emissions are effectively eliminated, pollution by NO_x, SO_2, and particulates becomes critical.

Further areas of research on this issue might concern an evaluation of the thermal pollution contributes by nuclear power plants or an evaluation of equipment efficiency in eliminating contaminants caused by the combustion of fossil fuels.

4. Average distance traveled by electric vehicles entered in the CACR.

5. Duprey, R. L., "Complication of Air Pollutant Emission Factors," Public Health Service, Department of Health, Education and Welfare, 1968.

VI

IV. A DISCUSSION OF AUTOMOTIVE FUELS USED IN THE CLEAN AIR CAR RACE

ROLE OF THE COMMITTEE

The organization committee encountered several large-scale logistical problems in preparing for the 1970 Clean Air Car Race (CACR), one of which was the supply of different fuel types to the entrant team test vehicles. At first, the standard policy called for each team to assume individual responsibility for securing and financing its own supply. By late spring, however, the committee was in a position to arrange for distribution systems for the most commonly used fuels. The committee had also accepted the responsibility for the design and construction of a cross-country "electric car expressway" along the CACR route.

With a rapid response from the CACR teams in returning their preliminary applications, the committee noted that internal combustion engine powered vehicles (Class I) appeared to dominate the entrant list, and that fuel selection usually fell into one of three areas:

1. natural gas, both liquid, (LNG) and compressed (CNG)
2. liquid petroleum gas (LPG)[1]
3. gasoline, both leaded and unleaded

Although the actual breakdown of fuel types would remain unknown until the entrants reported to MIT for the week of pre-race testing, initial plans assumed that most teams would be using one of the three possibilities listed above.

Concern for the hazards of transporting potentially dangerous fuels led the committee to establish contact with the Federal government's Department of Transportation (DOT) for the purpose of investigating national and state safety regulations on this matter. Law required that a petition be filed by any individual transporting fuel not in compliance with the procedure described in the Federal Register (Volume 33, Number 108, parts 171-190). To assist entrant teams in this matter, the committee sent a representative to the appropriate government offices for the purpose of describing the CACR event, while simultaneously endorsing petitions received by DOT from the entrants. Due to time limitations, the Federal government gave special consideration to the CACR, and those entrants using hazardous fuels obtained their permits with only minimal difficulty.

By mid-summer, the committee was setting up complete fuel distribution systems for LNG, LPG, and electrically powered vehicles. It was unfortunate,

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1. The primary component of LPG is propane.

however, that time and manpower limitations did not permit the committee from assisting all group fuel users, most of which did not experience any insurmountable problems.

SUMMARY OF THE FUEL TYPES USED

The final breakdown on the number of teams using each fuel type is shown in Table VI-1. The most common fuel, LPG, was used by sixteen of the 43 entrants (37%).

Table VI-1: Fuel Type Breakdown of CACR Entrants

Fuel Type	Total Users
Liquid Petroleum Gas (LPG)	16[a]
Electricity	8[b]
Unleaded Gasoline	7[c]
Liquid Natural Gas (LNG)	4
Compressed Natural Gas (CNG)	3
Leaded Gasoline	2
Methanol	2
Diesel Oil	1
Lead Sterile Gasoline	1
Aviation Fuel (JP4)	1
Kerosene	1[d]

Due to the unusually short development time (no more than five months in most cases), many student teams were forced to utilize conventional engine systems and a large number of ICE entrant applications were received early in the competition. With low exhaust emissions being of prime importance, a ready-made solution appeared to be the selection of a substitute for gasoline, namely, a less complex hydrocarbon fuel such as LNG, CNG, or LPG. These fuels are advantageous for two reasons: 1) There are fewer problems with vaporization of the fuel prior to combustion during a cold start of the engine, and 2) the engine can run leaner, thus admitting fewer hydrocarbon chains to the combustion chamber.

Therefore, with only slight engine modifications necessary (some standard conversion kits are available commercially), many entrants quickly converted their power plants to run on one of these gaseous fuels. Had the 1970 CACR been conceived and announced at an earlier date, the number of entrants using other fuel types would very likely have increased.

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a. Includes one hybrid and one steam entrant
b. Includes all three hybrid entrants
c. Includes two hybrid entrants
d. Steam entrant

DISCUSSION OF THE FUEL TYPES USED

A comparison of the basic data on all fuel types used in the CACR can be found in Tabel VI-2.

The following sections will discuss the use of the various fuels used in the CACR mentioning the entrants, supply source and distribution system for each fuel. A description of each entrant's vehicle fuel system is included in Appendix B.

A. Leaded Gasoline

With few exceptions, the automobile of today was designed to operate on leaded gasoline. Tetraethyl lead is a gasoline additive used to increase the octane rating and to permit higher operating temperature and pressures within the engine cylinders. The initial use of tetraethyl lead resulted from the discovery that engine knock could very easily be eliminated with this additive. Another positive effect was the lead deposits on the cylinder head which provided a cushion for the valves.

Two entrants in the CACR ran exclusively on leaded gasoline: LSU (31) and WPI (33).[2] Both vehicles were 1970 American-made automobiles containing a standard internal combustion engine. Refueling for each was executed at commercial service stations on the route, and fuel was carried in standard tanks.

B. Unleaded Gasoline

Nearly all of the lead particulate emissions in the atmosphere are attributable to the tetraethyl lead additive in commercial gasoline. In an attempt to eliminate this and because they were using catalytic reactors, seven entrants in the race ran on unleaded gasoline. They were: UC Berkeley (30), WPI (32), Michigan (34), Michigan (35), Wisconsin (37), MIT (70), WPI (71).

While unleaded gasoline has been made commerically available since the CACR, it was unavailable at most common service facilities until and including the race. During the spring, one entrant school (Wisconsin) was able to solicit an adequate supply of unleaded gasoline from Chevron (California) for use during the CACR. When additional applications were received from entrants also considering unleaded gasoline, the committee referred them to the Wisconsin team. The first two additional schools doing so entered into a fuel sharing agreement; however, subsequent entrants were asked by Wisconsin to make their own arrangements as the Chevron fuel was not sufficient to supply all requesting test vehicles.

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2. All entrants will be identified by their common abbrieviated name and vehicle number in this chapter. See Appendix A for complete name.

Table VI-2: FUEL CHARACTERISTICS

	Specific Gravity (H_2O=1)	Heating Value (Btu/lb)	Boiling Temp. at 1 atm. (°F)	Storage Pressure (p.s.i)	Storage Temperature (°F)
Gasoline-leaded & unleaded (values for isooctane)	0.69	20,556	211	Atm.	Ambient
Liquefied Petroleum Gas (propane)	0.5	21,484	-44	75-150	Ambient
Compressed Natural Gas	---	23,650	---	2,200	Ambient
Liquefied Natural Gas (methane)	0.3	23,650	-259	75-120	-259 (approx.)
Methyl Alcohol (methanol)	0.79	9,770	149	Atm.	Ambient
Diesel Oil	---	19,600*	475*	Atm.	Ambient
Kerosene	---	18,300*	---	Atm.	Ambient
Aviation Fuel (JP4)	---	18,300*	---	Atm.	Ambient

*Approximate values: ± 10%

At this time the committee, on behalf of the unleaded entrants, approached a large midwestern oil company and requested that additional unleaded gasoline be donated to the CACR. The company refused. However, after being informed of the situation, Engelhard Industries[3] offered to purchase and ship the necessary additional fuel.

Unlike the commercially available leaded gasoline, the unleaded fuel was stored on or near the impound area at each host campus. Upon arriving, the entrant vehicle would proceed directly to the refueling area and tank up for the following day's run. The trail vehicle crew would then fill several standard 5-gal. containers with enough additional fuel to sustain the test vehicle for the entire leg. This "piggy-back" method was used by all unleaded-gasoline entrants, with refueling taking place at various locations off the interstate highway.

C. Lead Sterile Gasoline

One entrant - Wayne State (36) - used lead sterile gasoline. Unlike unleaded gasoline, lead sterile fuel has had all traces of lead removed[4] and is available only as a testing fuel. For this particular entrant, fuel for the entire route was carried in the trail vehicle before being transferred to an 18-gal. polyethylene tank that had replaced the conventional tank in the test vehicle.

D. Liquid Petroleum Gas (LPG)

As mentioned previously, the most commonly used fuel in the CACR was LPG. The sixteen entrants using LPG included: San Jose State (10), Stanford (11), UC Berkeley (12), USF (15), Evansville (16), Tufts (17), WPI (18), Buffalo State (19), Villanova (20), SMU (21), Wisconsin (22), St. Clair (23), Whitworth (24), Putnam City West (52), Toronto (75), and UCSD (80). Fuel system modification procedure called for the entrants to replace standard fuel tanks with ASME-approved pressure vessels to carry the LPG (HD-5) under moderate pressure. The LPG can be handled and transferred from supply tank to vehicle fuel tank by means of pressure hoses with quick-connect couplings. Putnam City West (52) also carried a pressure vessel for CNG. This could be recharged overnight, and used as an alternative to LPG for limited range travel.

When it became apparent that a large number of entrants would use LPG, the committee contacted the National LP-Gas Association in Chicago and re-

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3. This corporation had a strong interest in the CACR, as it had donated catalytic reactors to many of the entrant teams.

4. The small amounts of lead present in the crude oil are not removed from gasoline during the refining process.

quested that it serve the CACR as a liaison in arranging refueling facilities. The NLPGA subsequently contacted LP-gas dealers approximately every 100 to 150 miles along the CACR route. In turn, the committee notified all LPG entrants of the developments and called a general meeting for these entrants during the pre-race week at MIT. During this session, an NLPGA representative distributed a route guide describing the location and services provided by some 62 cooperating LPG dealers.

Unfortunately, one major complication arose concerning the LPG provided by many of the dealers. The CACR test vehicles required a clean form of LPG to prevent regulator fouling. In many instances, impurities such as compressor oil in the commerical LPG caused minor fuel system breakdowns.

E. Compressed Natural Gas (CNG)

Three of the entrants - Caltech (1), Caltech (2), and Georgia Tech (6) - modified standard ICE's to run on compressed natural gas, which is almost completely methane (CH_4). Each test vehicle's standard fuel tank was replaced by a series of high pressure vessels installed in the vehicle's trunk, and the fuel system was adapted with a Pneumetrics conversion kit to accept natural gas.

Although CNG can be stored at ambient temperatures, high storage pressure (over 2000 psi) is necessary for storage space considerations. Even at these pressures, CNG requires over twice the volume of liquid or liquefied gaseous fuel for the same amount of fuel (by weight).

For the these entrants the problem of obtaining a supplier was critical, in that compressing the gas required both high-pressure storage cylinders and a sophisticated compressor. The industrial sponsors for these teams provided trucks in which an adequate supply of CNG for the entire race route was transported, and refueling occurred at various exits along the interstate highway.

F. Liquid Natural Gas (LNG)

The four entrant test vehicles running on liquefied methane (CH_4) were San Diego State (3), Lowell Tech (4), Northeastern (5), and Arizona (51). With this fuel type, the standard gasoline tanks had to be replaced by double-walled, vacuum insulated, stainless steel tanks to contain the LNG (under moderate pressure). The conversion of the fuel supply system in the vehicle required a different procedure than that used for CNG because the liquid natural gas had to be vaporized before being mixed with engine intake air. The LNG is delivered to a carburetor (mixer) through a series of valves, pressure reducers, and a vaporizer.

The obvious advantage of storing the fuel in liquid form was the increased range of travel afforded by a single tank in the trunk. It should be noted that pressure builds as the fuel absorbs heat from its environment, and LNG cannot be stored for more than 24 hours without venting to the atmosphere. A typical commuter vehicle using LNG would probably use enough fuel daily to eliminate the necessity of venting.

One entrant - Arizona (51) - had intended to use a hybrid fuel of 90% methane (CH_4) and 10% hydrogen (H_2) by weight. Although this was not done during the race, the hydrogen would have been carried in a pressure vessel, and mixed immediately before combustion. The advantage of this plan is that methane-hydrogen mixtures can burn exceedingly lean and thus substantially reduce emissions.

The problem of fuel supply was solved by the Lowell Gas Company (Lowell, Massachusetts), which agreed to donate liquefied natural gas for the LNG-fueled cars. The company, while having the necessary license to transport LNG in many northeastern states, found it necessary to secure permits for all other states along the CACR route. The fuel was furnished from an 11,000 gallon tractor trailer which accompanied the race caravan. Vehicle refueling was accomplished at each impound area.

G. Methanol

One entrant - Stanford (41) - used methyl alcohol (CH_3OH), or methanol as it is commonly called. A second entrant - Incline Village (50) - ran on a half and half mixture of methanol and gasoline. Storage was by conventional fuel tank, and as with unleaded gasoline, a master supply was forwarded to each impound area where the entrant vehicle refueled at the conclusion of a days run. The trail vehicle carried an excess supply in the previously mentioned "piggy-back" method.

H. Diesel Oil

Although not common, automobiles are manufactured which run on diesel fuel. One entrant, UCLA (42), using a Japanese-built diesel engine (Diahatsu Co.), ran exclusively on this fuel type, which was commercially available and easily stored in the vehicle's conventional fuel tank.

I. Kerosene

One of the Rankine class entrants (class II), WPI (83), had planned to use kerosene. While commercially available in many ordinary service stations, the entrant did not go beyond the city limits of Boston.

J. Aviation Fuel

One entrant - the MIT turbine (90) - used JP4. However, the engine itself was on loan from the U. S. Air Force, and as a result was not intended to operate as an automotive power plant. Storage of fuel on the vehicle itself was in an aluminum tank with baffles and lined with reticulated foam. Refueling en route posed some problems, as an airfield with fuel capabilities had to be located at each refueling interval.

K. Electric Power

The five entrant teams in the electric vehicle class included: Georgia Tech (61), BU (62), Iona (64), Cornell (65), and Stevens Institute (66). Although the cross-country recharging station network was available to all the electric entries, Georgia Tech and BU teams chose to demonstrate the principle of "battery-pack switching." Each team employed two sets of battery banks, one to operate the entrant vehicle while the other was being recharged by a generator located in the trail vehicle. It should be mentioned that the actual task of battery switching every hour was physically demanding. The weight of a bank of the lead-acid batteries often approached 1500 lbs. and required the services of all members of the driving team.

The other electric vehicle entrants made use of recharging facilities while the three electric hybrid carried optional connectors to these charging stations.

The problem of locating the new recharging facilities had been reviewed by the participants in the 1968 Electric Car Race. In setting up the final CACR cross-country route, the committee consulted with the participants in the 1968 Electric Car Race. With their recommendations, the expanded plans called for a series of permanent "charging stations" every 50 to 70 miles along the route. Two members of the committee spent most of the summer coordinating the placement of these charging stations while the construction of the units was handled by Electric Fuel Propulsion, Inc. of Detroit.

With assistance from the Edison Electric Institute and the National Rural Electric Cooperative, the committee was successful in contacting the individual utilities along the route and convincing them to purchase, at cost of manufacture, the charging stations. Electrical power, while accurately metered by these stations, would be provided at no cost to race entrants. By late August, the nation's first "Transcontinental Electric Expressway" had been completed from Boston to Pasadena.

A typical charging station (Fig. VI-1) consisted of weather-proof plastic housing (6' x 2' 2" x 1'3"), reinforced with rectangual steel tubing, and containing a Westinghouse 400-amp circuit breaker (LAB-3400 or equivalent). The connector was a Pyle-National 350-amp, 6-pin rectangular on ten feet of 4/0 insulated, flexible copper cable rated for 300 amps.

Sponsoring utilities were asked to purchase (@ $450 each), install, connect, and maintain their respective stations. A list of these locations is found in Table VI-3.

Actual recharging of the vehicles varied in length from 25 to 90 minutes. Thus, it was apparent that the electric cars would take almost twice the prescribed time to complete each leg, it not longer. Thus, those electric cars which made it to California under their own power arrived two days later than the race caravan. This emphasized the point that electric vehicles are mainly proposed for transportation within urban areas and are not suitable for transcontinental travel.

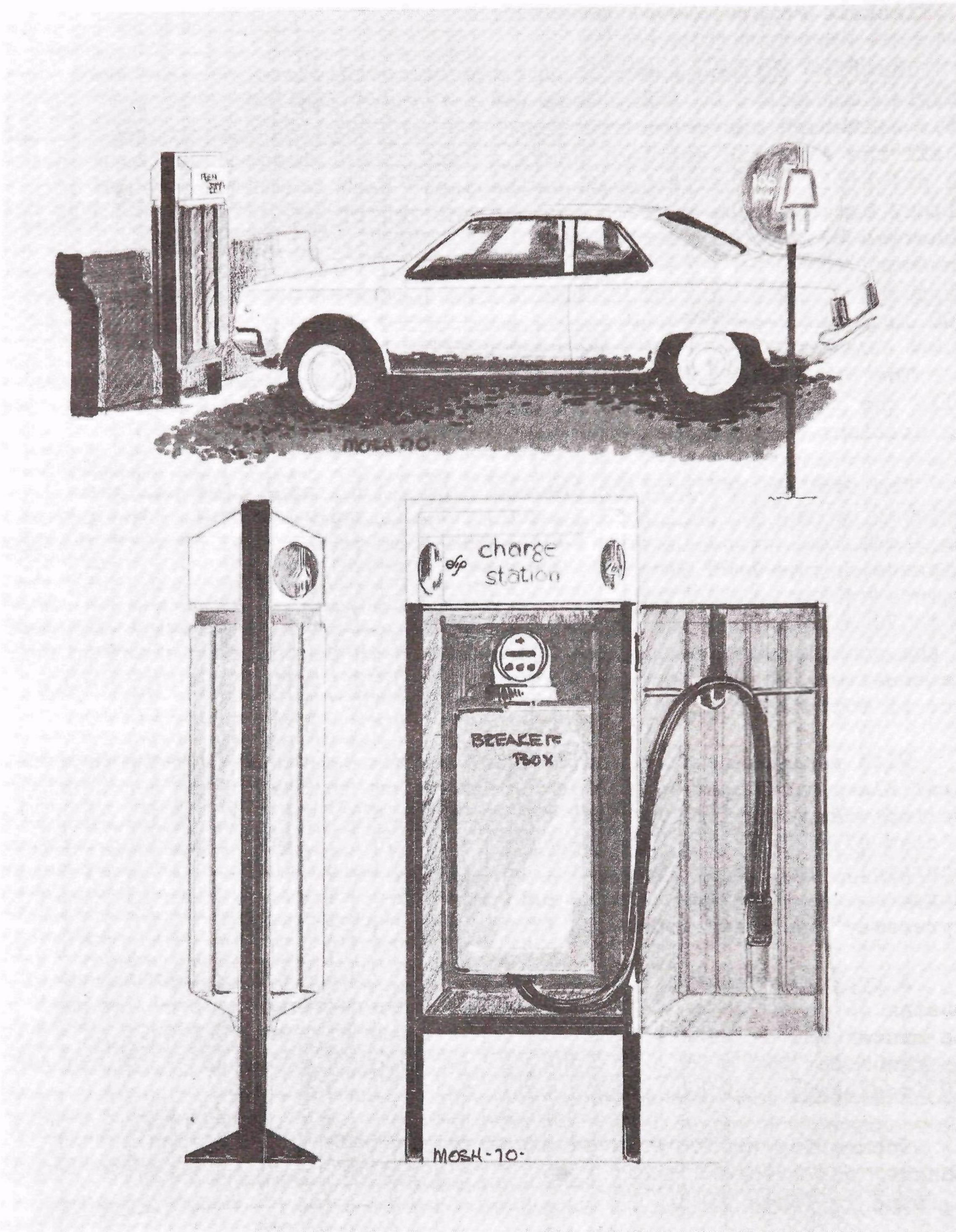

Fig. VI-1: CACR Electric Charging Station

Table VI-3

ELECTRIC CAR EXPRESSWAY
CHARGING STATIONS
LOCATIONS

Station Location	Mileage to next station
1. Cambridge, Massachusetts	45 miles
2. Worcester, Massachusetts	44 miles
3. Springfield, Massachusetts	50 miles
4. Lee, Massachusetts	47 miles
5. Albany, New York	53 miles
6. Canajoharie, New York	43 miles
7. Utica, New York	53 miles
8. Syracuse, New York	79 miles
9. Rochester, New York	37 miles
10. Batavia, New York	56 miles
11. Niagara Falls, New York	42 miles
12. Hamilton, Ontario, Canada	40 miles
13. Toronto, Ontario, Canada	64 miles
14. Kitchener-Waterloo, Ontario, Canada	54 miles
15. London, Ontario, Canada	69 miles
16. Chatham, Ontario, Canada	55 miles
17. Windsor, Ontario, Canada	50 miles
18. Ann Arbor, Michigan	42 miles
19. Jackson, Michigan	64 miles
20. Kalamazoo, Michigan	47 miles
21. Benton Harbor, Michigan	68 miles
22. Gary, Indiana	62 miles
23. Kankakee, Illinois	62 miles
24. Rantoul, Illinois	14 miles
25. Champaign-Urbana, Illinois	49 miles
26. Mattoon, Illinois	63 miles
27. Vandalia, Illinois	68 miles
28. St. Louis, Missouri	65 miles
29. Sullivan, Missouri	40 miles
30. Rolla, Missouri	58 miles
31. Lebanon, Missouri	48 miles
32. Springfield, Missouri	72 miles
33. Joplin, Missouri	45 miles

Station Location	Mileage to next station
34. Vinita, Oklahoma	56 miles
35. Tulsa, Oklahoma	53 miles
36. Stroud, Oklahoma	54 miles
37. Oklahoma City, Oklahoma	70 miles
38. Weatherford, Oklahoma	59 miles
39. Sayre, Oklahoma	61 miles
40. McLean, Texas	72 miles
41. Amarillo, Texas	75 miles
42. Plainville, Texas	50 miles
43. Lubbock, Texas	57 miles
44. Seagraves, Texas	46 miles
45. Andrews, Texas	35 miles
46. Odessa, Texas	37 miles
47. Monahans, Texas	40 miles
48. Pecos, Texas	51 miles
49. Kent, Texas	70 miles
50. Sierra Blanca, Texas	35 miles
51. Fort Hancock, Texas	49 miles
52. El Paso, Texas	53 miles
53. Las Cruces, New Mexico	59 miles
54. Deming, New Mexico	60 miles
55. Lordsburg, New Mexico	74 miles
56. Wilcox, Arizona	79 miles
57. Tuscon, Arizona	71 miles
58. Casa Grande, Arizona	62 miles
59. Gila Bend, Arizona	74 miles
60. Tacna, Arizona	44 miles
61. Yuma, Arizona	57 miles
62. El Centro, California	32 miles
63. Ocotillo, California	22 miles
64. Boulevard, California	24 miles
65. Alpine, California	45 miles
66. Del Mar, California	40 miles
67. San Onofre, California	40 miles
68. Santa Ana, California	40 miles
69. Pasadena, California	

COMMENTS AND IMPLICATIONS

The CACR managed to display 43 entrant vehicles that operated on 14 different fuels or combinations thereof. While the major thesis was directed toward the system producing the least atmospheric contamination, it is most difficult to evaluate the effects of the various fuels on exhaust emissions for two reasons:

1) Some representative fuels were used in several entrant vehicles while other fuels were used in but one vehicle. Therefore, statistical comparisons between exhaust emissions data based on fuel type would not be reliable.

2) The various types of modifications on individual power plants are numerous in regard to the engine size, and displacement, number of cylinders, and exhaust configuration. Thus, a cross-comparison would again be difficult since the systems have no common standard.

However, certain general clarifications can be made between the fuels in discussing the economic availability and distribution systems. The committee has not attempted to investigate those issues of interest to the economist in natural resource allocation, but several more obvious arguments may be brought forward and the reader allowed to form his own opinions.

Economic Availability

Note that the fuel types used in the CACR may be divided into three somewhat general categories:

a) By-products or distillates of petroleum--gasoline, propane, diesel oil, aviation fuel, kerosene.

b) Natural gas in either liquid (LNG) or gaseous (CNG) state.

c) Electrical power.

Note that the first two classifications are definitely derivatives of what are referred to as fossil fuels. However, a complication arises in that the production of electrical power--the third category--is still almost completely dependent on electrical generating plants fired by fossil fuels[5]. Therefore, the first question appears to be which fuel do we wish to produce from the natural resources we already have?

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5. A small fraction of plants operate on hydro and nuclear sources.

From a pollution standpoint, gaseous fuels (propane, natural gas) appeared to contribute less to motor vehicle-contamination; however, no attempt has been made to weight the industrial pollution caused by crude cracking processes. Secondly, pollutants most critical in electrical power production from a stationary source are the sulphur oxides, oxides of nitrogen and particulates[6]. Thus, the issue of amounts emitted and comparative toxicity arises. Are sulphur oxides more harmful to health and property than carbon monoxide and hydrocarbons?

From a capital investment standpoint, the continuation of large-scale production of conventional fuels would not require the retooling of existing refinery facilities. Recognizing that the cracking process is quite complex, a redefinition of product priorities available from crude would most assuredly mean additional investments.

From a fuel modification standpoint, the most often discussed alternative is the conversion from leaded premium to unleaded gasoline.

This raises the key issue of what octane rating must be maintained. While no answer is quickly available, it should be remembered that a decrease in the octane rating will lower thermal efficiency. Estimates have run from six to ten per cent reduction from present values, and the cost to the consumer due to this decreased efficiency would not be negligible.

Finally, from the viewpoint of natural resource reserves, it appears that the presently discovered petroleum supplies will adequately support America's accelerating consumption for several decades. A further economic investigation would involved an assessment of the national oil import quota policy.

Distribution Systems

While it was necessary for many of the entrants to "piggy-back" their fuel supply each day, there is little doubt that the petroleum products could be distributed in a service station facility network similar to those that now exist for gasoline. Unleaded gasoline, diesel oil, kerosene, aviation fuel, and methanol could use the existing distribution and storage facilities with little or no revision.

The storage of compressed or liquid gases (LPG, LNG, CNG) presents a critical investment, in that they require the installation of pressure vessels in both the vehicle and the service locations. This raises an issue of safety. Concerning vehicle storage vessels, the technical report of one CNG entrant stated that his fuel system was constructed entirely with Underwriter's

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6. See Chapter V for a analysis of electric vehicle emissions due to electric generating plants.

Laboratory and ASME approved components. In addition, a group of safety engineers employed by an insurance underwriting firm adjudged that his system " . . . should present no unusual operating problem or excessive exposure to employees or guests."

In terms of distribution, it appears that electrical power shares the same advantages as liquid petroleum by-products. A metered connector could be installed at agent stations, and the power would be sold. Supporters of the electrical vehicle concept are quick to point out that urban commuters travel no more than 50-60 miles by car during the working day. This is within the range of power storage requirements using today's battery technology, and lends itself to the concept of recharging the "urban" car overnight within the owner's garage or adjacent facilities.

Recharging time[8] has been shown to be a handicap; however, the technique employed by two entrants of switching battery packs is most interesting. If battery configurations were standardized, then the vehicle carrying a "spent" pack would simply "purchase" from the nearest agent a recharged pack after pulling his pack and leaving it for a future consumer.

As a final point concerning electric vehicles, it was apparent that stored energy electric cars were not a feasible solution for cross-country (or intercity) travel. At present, it appears that the single most pressing problem lies in the area of battery development[9]. The entrants ran on a bank of conventional lead-acid batteries connected in series; these have limited storage capacity and high weight.

The committee has attempted to correct the misconception that electric vehicles did "poorly" in the 1970 CACR. The 3,600-mile trek was designed to measure vehicle reliability, and was never intended that an electric car be compared with more conventional vehicles in Interstate highway driving. They remain an interesting possibility for urban transportation.

In summary, the reader has seen that the issues surrounding fuel selection are quite often the concern of the economist. When taken in context with the remainder of this report, it is readily seen that picking the "best" vehicle to operate on the "best" fuel is a problem of trade-offs and requires more than just the skills of the engineer.

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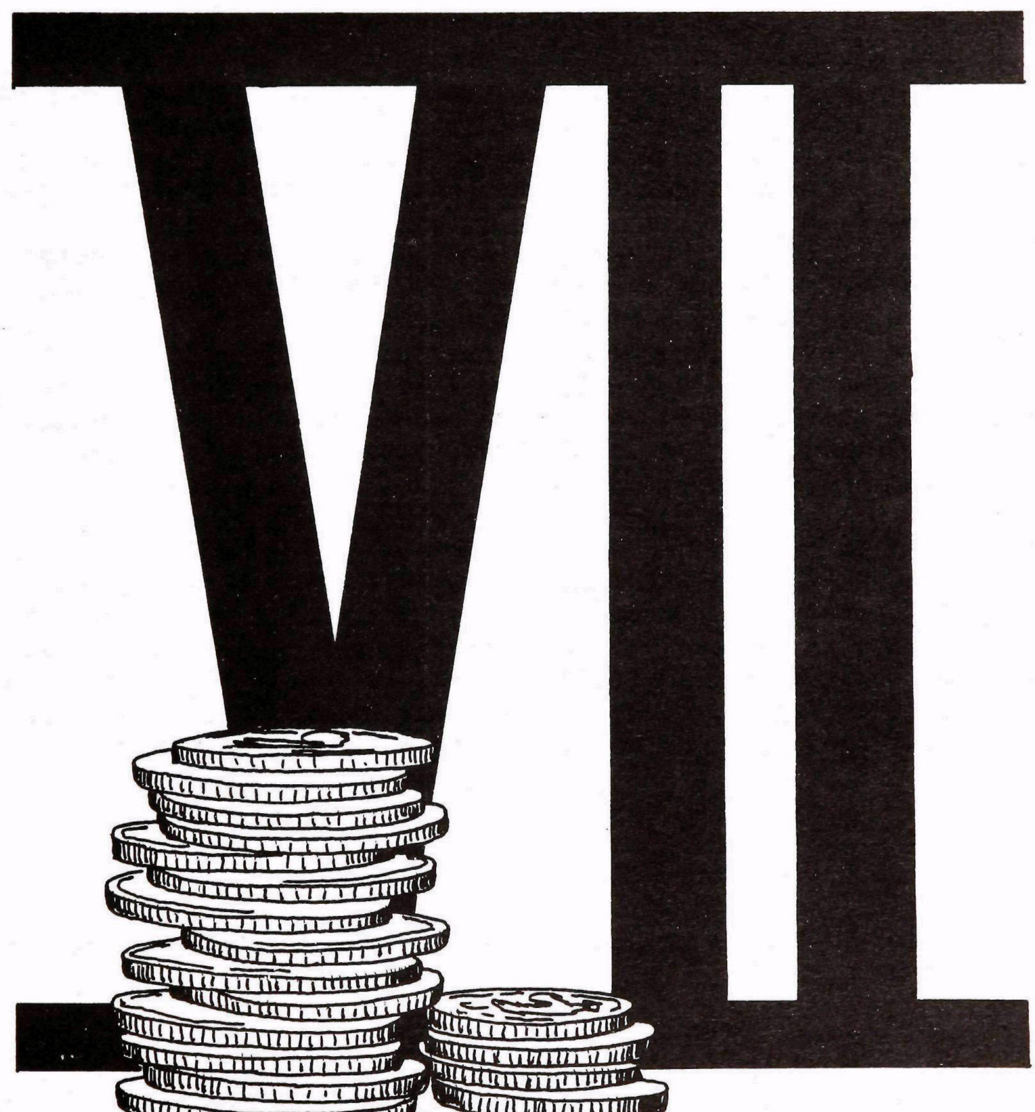
8. The CACR vehicles spent from 25 to 90 minutes per charge during the race.

9. As of this writing, the automobile industry was experimenting with a sodium-sulphur battery that would greatly improve the energy density characteristics of a portable storage source.


VII

VII. WHAT IT COST TO HAVE A CLEAN AIR CAR RACE

SUMMARY

The combination of planning for and staging the 1970 Clean Air Car Race (CACR), as well as conducting a follow-up documentation effort has resulted in an accumulation of funds and services totaling on the order of $.75 million. This figure is calculated on the basis of both dollars and contributions of manpower and equipment which the committee realized during its period of operation—February, 1970, to January, 1971.

Altogether, the teams involved in the CACR, including preliminary entrants who never reached the starting line, numbered slightly over 100. It is plausible to estimate that they spent between $.5 and $.75 million in preparing their vehicle entries for the competition. The cost range has been computed on the basis of estimates for hardware acquisition, use of testing facilities, student-faculty manpower, and cross-country travel.

A cost estimate for the peripheral efforts of industrial and government concerns has not been worked out. The figure could reasonably lie anywhere between $.1 and $.5 million.

More than 1000 individuals from educational institutions participated directly in either the design and construction of vehicle power plants or the administration, public relations, and fund raising aspects of the individual team efforts.

In summary, anywhere between $1.35 and $2.0 million is the total cost estimate for the staging of the 1970 Clean Air Car Race. If as many as 1000 individuals from various educational institutions did in fact participate in the CACR, then a reasonable cost per capita figure lies somewhere between $1,350 and $2,000 for a year's worth of educational activity. Interestingly enough, a year's worth of education at today's private institutions, such as MIT, costs more than $2,000.

SECTION A

A HISTORY OF THE CACR FUND RAISING CAMPAIGN

When the Clean Air Car Race was officially launched with a public announcement in late November of 1969, financial support for the proposed undertaking was practically non-existent. Dr. Milton Clauser of the MIT Lincoln Laboratories had submitted a request to the General Motors Corp. for a grant of $100,000 to cover the cost of organizing the competition and providing funds for distribution to some of the entrant teams. Action had not been taken on Dr. Clauser's request at that time, and, as matters turned out, a final decision would not be forthcoming until mid-April of 1970.

Despite the lack of definite financial support, the organization committee was formed and the assistance of MIT's Corporation chairman, Dr. James Killian, was immediately requested. Because the committee had commenced its activities without any operating funds, Dr. Killian acted quickly by seeking personal contributions from members of the MIT Corporation and Planning Committee. Convinced of the CACR's merits with respect to engineering education in the university, Dr. Killian was able to secure many pledges for support and several thousand dollars by early spring.

While these initial funds were being secured, the committee drew up a preliminary budget to project the scope of CACR operations and assess the corresponding financial need. The following major expense items added up to roughly $125,000 as a reasonable first-cut estimate of what it might cost to have a Clean Air Car Race:

1. Summer salaries for the organization committee members.
2. Salaries for other office personnel.
3. Office operations: materials, equipment, printing, xerox, postage, and telephone.
4. Committee and observer travel expenses.
5. Pre-race activities at MIT: housing, seminars, banquets, machine shop, etc.
6. Race operations: accommodations, meals, communications, security, insurance, etc.
7. Post-race activities: seminars, awards, banquets, data analysis, housing, and meals.

Please note that the above list had made no allowance for the extensive performance and exhaust emissions testing to be conducted during the competition. The expense involved had led the committee to hope that the automotive industry would donate these services--including the necessary equipment, facilities, and manpower--without which the CACR would have been truly crippled.

The need for increased funds and services continued as the scope of the CACR expanded and formerly unconsidered details received attention. The General Motors Corp. provided a very strong shot in the arm to the overall event by presenting the committee with twenty 1970 Chevelles plus a $2,000 research and development grant per vehicle for distribution to the entrant teams. In addition, two Chevelles and a $4,000 grant were given to the committee for its summertime activities, which included several coast-to-coast trips in preparation for the CACR cross-country travel. The Ford Motor Co. paralleled the GM contribution by making available its Mobile Emissions Laboratory for the week of pre-race testing in Cambridge, as well as two station wagons and an Econoline van for committee use. The required service functions for the CACR were being knocked off one by one, but the cash-in-hand outlook had still not progressed satisfactorily.

The Federal government's National Air Pollution Control Administration within the U.S. Department of Health, Education and Welfare (now the Air Pollution Control Office within the Environmental Protection Agency) agreed to foot the travel expenses for all committee members throughout the period of organizational activity as well as the competition itself—the cost estimate being on the order of $20,000. Additional funds to cover the travel expenses of all CACR observers came from NAPCA just as the race was about to begin. NAPCA officials also provided the necessary manpower to coordinate the exhaust emissions testing program for all CACR vehicles both prior to and during the competition. A final long-range support function was provided by this agency when they suggested and then financed the CACR documentation effort, which included several films and a number of publications.

During this time, MIT had come to the committee's aid with as great a support capability as could have been desired. The key to committee financial problems was without a doubt provided by Dr. Killian, who had now done the necessary groundwork for the committee to make a request to the foundations; mainly through his efforts grants totalling $33,000 were eventually obtained from the Rockefeller, Cabot, and Mellon foundations. From the outset, MIT had allowed the committee the use of its public relations office to disseminate information to the media and the CACR entrant teams. The other necessary services for pre-race activity at MIT were also arranged for and contributed with the expectation that the committee treasury would need every donation that it could get.

The cost of vehicle performance testing was eliminated when the Cornell Aeronautical Laboratories loaned the committee the necessary equipment to make the test measurements. Part of the Hanscom Field Air Force facilities in Bedford, Massachusetts, provided the committee with adequate space to conduct the testing.

During July and August, members of the committee worked with the Edison Electric Company and the National Rural Electric Cooperative to arrange for the electric vehicle charging stations. Thirty-six utility companies altogether were approached with the request that they purchase and set up a total of sixty charging stations. Similar refueling facilities were established for vehicles powered by liquefied petroleum gas (LPG).

Numerous contributions of dollars and services from many other industrial firms helped the committee complete its financing. An assessment of total funds and services accumulated in staging the CACR is presented in Section B of this chapter, and a statement of actual committee operating expenses follows in Section C.

In conclusion, one point should be remembered:

At no time during the fund raising effort did the committee grant "special favors" in return for assistance. The committee dealt with industries in as non-commercial a fashion as possible and required that any permissible advertising be discreetly done.

SECTION B

ESTIMATE OF FINANCIAL SUPPORT ACCUMULATED

Financial support received by the CACR committee can be divided into two distinct categories: actual funds donated and goods and services supplied.

Actual funds contributed totaled nearly $.3 million and may be broken down as follows.

I.	MIT Corporation	$ 17,400
II.	Foundations	33,000
III.	Federal Government	230,100[1]
IV.	Industry	8,100
	Total	$288,600

The second category of support, that of goods and services, is not as easily determined. The committee has reviewed the assistance received through its requests, and has subdivided the contributions as follows:

I.	MIT	$ 6,100
II.	Federal Government	73,000
III.	General Motors Corporation	98,000
IV.	Ford Motor Company	53,500
V.	Other Industries	189,700
VI.	Emission and Performance Testing Facilities	39,000
VII.	Host Universities and Communities	16,800
	Total	$426,100

1. Documentation contract awarded by NAPCA to MIT.

SECTION C

COMMITTEE OPERATING EXPENSES

The following page provides an estimate of all expenditures incurred by the CACR Organization Committee in preparing for, staging, and documenting the 1970 Clean Air Car Race.

The table gives a total breakdown of the expenditures incurred, the time period during which they occurred, and the approximate amount. The four major categories of expenses are: Salaries and Wages, Operating Expenses, Race Activities, and Documentation. The Race Activities classification covers all those costs incurred by or because of the period August 17 to September 4. The Documentation figures are estimates as the final charges are uncompleted.

CLEAN AIR CAR RACE COST SUMMARY

	March-July	August	Sept.-Feb.	Totals
Salaries & Wages				
MIT students & faculty	5,730	3,000	13,240	21,970
Hourly Personnel	420	420	850	1,690
Secretarial & Clerical	2,740	3,140	5,670	11,550
Operating Expenses				
Xerox & Graphic Arts	1,090	790	760	2,640
Audio Visual	30	300	170	500
Office Supplies	130	130	400	660
Telephone	1,750	1,510	1,740	5,000
MIT Entrant Teams		6,000		6,000
Publications		4,310		4,310
Housing		90	90	180
Postage & Shipping		280	130	410
Trophies & Plaques		1,340	1,110	2,450
Travel			1,800	1,800
Miscellaneous & Petty Cash	710	1,030	620	2,360
Committee			310	310
Race Activities				
Insurance for Observers		930		930
Security & Police		1,760		1,760
MIT Physical Plant	20	2,550	20	2,590
Banquets		3,460		3,460
Housing		90		90
Parades		2,210		2,210
Race Execution		6,120		6,120
Documentation				
Film Contract		42,630	127,370	170,000
Film Prints			10,000	10,000
Report			3,500	3,500
Computation			3,000	3,000
TOTALS	12,620	82,090	169,780	265,490

APPENDICES

APPENDIX A

CLEAN AIR CAR RACE ENTRANT TEAMS

Number	School	Engine/Fuel	Body
1	California Institute of Technology, Pasadena, Calif.	ICE/CNG	'70 Hornet
2	California Institute of Technology, Pasadena, Calif.	ICE/CNG	'70 Ford Ranchero
3	San Diego State College San Diego, Calif.	ICE/LNG	'70 Ford
4	Lowell Technological Institute, Lowell, Mass.	ICE/LNG	'70 Chevelle
5	Northeastern University Boston, Mass.	ICE/LNG	'70 Fairlane
6	Georgia Institute of Technology, Atlanta, Ga.	ICE/CNG	'70 Ford sedan
10	San Jose State College San Jose, Calif.	ICE/LPG	'70 Toyota
11	Stanford University Stanford, Calif.	ICE/LPG	'71 Mercury Capri
12	University of California Berkeley, Calif.	ICE/LPG	'70 Plymouth
15	University of South Florida Tampa, Florida	ICE/LPG	'70 El Camino
16	University of Evansville Evansville, Ind.	ICE/LPG	'69 Olds Cutlass
17	Tufts University Medford, Mass.	ICE/LPG	'70 Chevelle
18	Worcester Polytechnic Institute, Worcester, Mass.	ICE/LPG	'70 Nova
19	Buffalo State University Buffalo, N.Y.	ICE/LPG	'61 Sprite
20	Villanova University Villanova, Pa.	ICE/LPG	'70 Mustang

A

Number	School	Engine/Fuel	Body
21	Southern Methodist University, Dallas, Tex.	ICE/LPG	'70 Mustang
22	University of Wisconsin Madison, Wis.	ICE/LPG	'69 Opel GT
23	St. Clair College Windsor, Ont., Canada	ICE/LPG	'70 Dodge Coronet
24	Whitworth College Spokane, Wash.	ICE/LPG	'70 Ford Maverick
30	University of California Berkeley, Calif.	ICE/unleaded gas	'70 Plymouth
31	Louisiana State University Baton Rouge, La.	ICE/ leaded gas	'70 Pontiac Lemans
32	Worcester Polytechnic Institute, Worcester, Mass.	ICE/unleaded gas	'70 Saab
33	Worcester Polytechnic Institute, Worcester, Mass.	ICE/ leaded gas	'70 Mustang
34	University of Michigan Ann Arbor, Mich.	ICE/unleaded gas	'70 Chevelle
35	University of Michigan Ann Arbor, Mich.	ICE/unleaded gas	'70 Chevelle
36	Wayne State University Detroit, Michigan	ICE/lead-sterile, gas	'71 Mercury Capri
37	University of Wisconsin Madison, Wis.	Ice/unleaded gas	'70 Lotus
41	Stanford University Stanford, Calif.	ICE/ methanol	'70 Gremlin
42	University of California at Los Angeles, Calif.	ICE/deisel oil	'65 Mustang
50	Incline Village High Sch. Incline Village, Nevada	ICE/methanol-gas	'69 Dodge wagon
51	University of Arizona Tucson, Arizona	ICE/LNG and hydrogen	'70 Plymouth Duster

Number	School	Engine/Fuel	Body
52	Putnam City West High School Oklahoma City, Okla.	ICE/LPG or LNG	'70 Opel
61	Georgia Institute of Technology, Atlanta, Ga.	Electric	Fabricated
62	Boston University Boston, Mass.	Electric	Fabricated
64	Iona College New Rochelle, N.Y.	Electric	'62 VW
65	Cornell University Ithaca, N.Y.	Electric	'70 EFP sedan
66	Stevens Institute of Technology, Hoboken, N.J.	Electric	Fabricated
70	Massachusetts Institute of Technology, Cambridge, Mass.	Electric-ICE hybrid/unleaded gas	'68 Corvair
71	Worcester Polytechnic Institute, Worcester, Mass.	Electric-ICE hybrid/unleaded gas	'70 Gremlin
75	University of Toronto Toronto, Ont., Canada	Electric-ICE hybrid/LPG	Fabricated
80	University of California at San Diego La Jolla, California	Steam/LPG	'70 Javelin
83	Worcester Polytechnic Institute, Worcester, Mass.	Steam/kerosene	'70 Chevelle
90	Massachusetts Institute of Technology, Cambridge, Mass.	Gas turbine	'70 Chevelle C/10 pickup

APPENDIX B

ENTRANT TEAM TECHNICAL REPORTS

This appendix includes, in outline form, the following information on each entrant vehicle:

1. Vehicle technical description
2. Performance data
3. Emissions data
4. Fuel economy

The large numbers in the upper right hand corner are entrant numbers and were inserted for easy reference.

Notes:

Hot Start tests: Minimum values used as cutoffs due to instrument inaccuracy are very low concentrations were

CO	1000 ppm
HC	10 ppm
NO_x	100 ppm

No reactivity factors were used for hydrocarbons.

Cold Start tests: Cutoffs were

CO	1.00 gm/mile
HC	0.12 gm/mile
NO	0.20 gm/mile

B

1

CALIFORNIA INSTITUTE OF TECHNOLOGY

Entrant: #1

Class: I.C.E. (Gaseous Fuel)

Team Captain: Michael Lineberry
Thomas Lab
California Institute of Technology
East California Blvd.
Pasadena, California 91109

Body and Chassis: 1970 American Motors Hornet

Vehicle Weight: 3840 lbs.

Power Plant: I.C.E. - standard 6-cylinder, 232 C.I.D.

Fuel: Compressed Natural Gas

Fuel System:

CNG - Variable venturi mixer, diaphragm controlled, mounted on carburetor intake. Fuel supplied from 12 scuba-type tanks in trunk. Two-stage pressure reduction from 2265 p.s.i. to 50 p.s.i. to 2 inches of water pressure.

Exhaust System:

Standard single-pipe

Emission Control:

25% excess air in air-fuel mixture results in:
1) More complete combustion, reduce CO.
2) Cooler flame temperature, reduce NO_x.

Vacuum spark advance eliminated to effect retarded spark - reduces NO_x and HC.

Modifications:

1) Passenger compartment sealed from trunk to keep out gas in case of a leak.

2) Radial tires installed.

3) Brake automatic adjustment device removed to reduce rolling resistance.

4) Installed shock absorbers with adjustable air inflation system in rear to level car.

5) Installed adjustable shocks in front, anti-sway bars, and faster ratio steering box to improve handling.

6) Installed constant speed control to improve economy.

7) Equipped car with citizen's band transmitter-receiver.

Performance Data: #1

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	7.7
0-45	13.2
20-50	11.4

2) Braking

Speed (mph)	Stopping distance (ft.)
30	66
51	138

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	79.2
Driver #2	86.8

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	80.5
30 Cruise	50'	64.0
Idle	10'	63.5

Emissions Data: #1

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.42	11	52
CO	1.00	1000	1000
NO	0.47	128	100

Part. (gm/mile): 0.09

Fuel Economy: #1

146.0 miles/million Btu

CALIFORNIA INSTITUTE OF TECHNOLOGY

Entrant #2

Class: I.C.E. (Gaseous Fuel)

Team Captain: Michael Lineberry
Thomas Lab
California Institute of Technology
East California Boulevard
Pasadena, California 91109

Body and Chassis: 1970 Ford Ranchero

Vehicle Weight: 4750 lbs.

Power Plant: Internal Combustion Engine (I.C.E.), 351 C.I.D. V-8 configuration

Transmission: 4-speed manual

Fuel: Compressed Natural Gas (or Gasoline, not used during CACR)

Fuel System:

1) CNG - Variable venturi mixer, mounted on carburetor intake. Fuel supplied through pressure regulators and valves from 4 tanks in trunk.

2) Gasoline - Standard fuel tank, lines, and carburetor.

Exhaust System:

Standard Single-pipe.

Emission Control:

Excess air (25%) in air-fuel mixture -
1) More complete combustion, reduction of CO.
2) Cooler flame temperature, reduction of NO_x.

Vacuum spark advance eliminated - retards spark (except at idle), reduces NO_x and HC emissions.

Performance Data: #2

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.3
0-45	10.0
20-50	7.6

2) Braking

Speed (mph)	Stopping distance (ft.)
27	36
50	120

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	79.0
Driver #2	82.4

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	80.5
30 Cruise	50'	63.0
Idle	10'	59.5

Emissions Data: #2

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	3.02	40	64
CO	2.76	1000	1000
NO	0.74	100	192

Part. (gm/mile): 0.01

Fuel Economy:

104.4 miles/million Btu

SAN DIEGO STATE COLLEGE

Entrant: #3

Class: I.C.E. (Gaseous Fuel)

Team Captain: Al Innis
c/o Dr. Robert Murphy
School of Engineering
San Diego State College
San Diego, California 92115

Body and Chassis: Ford Cortina

Vehicle Weight: 1825 lbs.

Power Plant: I.C.E., 4 cylinder, 97.51 C.I.D.

Transmission: 4-speed manual, fully synchronized

Fuel: Liquefied Natural Gas

Fuel System:

Variable venturi (diaphragm) mixer, fed by vaporizer/pressure - regulator from double-walled, vacuum-insulated fuel tank. Engine water circulates through regulator to vaporize fuel. Fuel tank has pressure-controlled vapor or liquid fuel feed.

Exhaust System:

Dual chamber catalytic reactor.

Emission Control:

1) Air/fuel ratio set at 19/1. Best balance to achieve low HC and CO emissions without raising No_x.

2) Ignition timing retarded 4° from stock (8° to 10°) to control NO_x.

Performance Data: #3

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.5
0-45	14.6
20-50	12.0

2) Braking

Speed (mph)	Stopping distance (ft.)
28	42
50	138

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	78.0
Driver #2	77.0

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	80.5
30 cruise	50'	69.0
Idle	10'	71.5

Emission Data:#3

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	1.02	66	94
CO	6.38	2100	3600
NO	0.59	132	414

Part. (gm/mile): 0.03

Fuel Economy: #3

228.0 miles/million Btu

LOWELL TECHNOLOGICAL INSTITUTE

Entrant: #4

Class: I.C.E. (Gaseous Fuel)

Team Captain: Victor Baur
Operations Center
Lowell Gas Co.
Willie & Dutton Sts.
Lowell, Mass. 08153

Body and Chassis: 1970 Chevelle, 4-door sedan

Vehicle Weight: 3800 lbs.

Power Plant: I.C.E., 350 C.I.D. stock V-8

Transmission: 3-speed turbohydramatic

Fuel: Liquefied Natural Gas

Fuel System:

Impco model 425 natural gas carburetor mounted on original throttle plate housing. Supplied by two Impco P.E. pressure converters (in parallel). Pressure converters receive fuel from vacuum-insulated tank through a heat exchanger heated by engine coolant. Vapor from converters passes through a gas meter before going to mixer. Pressure-regulated vapor or liquid fuel feed provided by pressure actuated solenoid valves.

Exhaust System:

Dual exhaust (no crossover) with an Engelhard PTX-4D235 platinum catalytic reactor just downstream of each manifold.

Modifications:

1) Exhaust gas heat riser passage blocked off - methane needs no pre-heating.

2) Heat riser valve removed

3) 195°F thermostat replaced by 160°F thermostat

4) Spark plug gap reduced to .025"

5) Timing set at 0° BTDC, vacuum advance eliminated

6) Air conditioning system removed to make room for conversion system

7) Gasoline tank & fuel pump removed

8) A 2.56/1 ratio rear end installed

9) Michelin "X" 195-15 steel radial tires installed

Performance Data: #4

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.8
0-45	13.1
20-50	12.2

2) Braking

Speed (mph)	Stopping Distance (ft.)
33	46
51	136

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	82.0
Driver #2	78.0

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	75.5
30 cruise	50'	63.0
Idle	10'	61.5

Emissions Data: #4

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.28	14	34
CO	9.21	1000	1000
NO	0.37	100	106

Part. (gm/mile): 0.02

Fuel Economy: #4

171.5 miles/million Btu

NORTHEASTERN UNIVERSITY

Entrant: #5

Class: I.C. E. (Gaseous Fuel)

Team Captain: Gregory Travers
c/o Charles Buckley
Boston Gas Co.
144 McBride St.
Boston, Mass.

Body and Chassis: 1970 Ford Fairlane, 4-door sedan

Vehicle Weight: 3800 lbs.

Power Plant: I.C.E., 250 C.I.D., 6-cylinder

Transmission: 3-speed automatic, factory stock

Fuel: Liquefied Natural Gas

Fuel System:

1) Storage - 20 gal. vacuum insulated tank mounted in trunk

2) Delivery - 1/2" copper tubes. Two tubes from tank, one for liquid, one for vapor. Liquid or vapor feed controlled by manually actuated solenoid valves. Driver reads tank pressure gauge on dash and selects liquid or vapor feed.

3) Vaporization - liquid is passed through a vaporization coil (warmed by forced air at ambient temperature).

4) Regulation and Metering - vapor delivered via 1/2" copper tubing to primary regulator (Fisher type Y600). Pressure reduced from 150 P.S.I. max. to 12" of water column. Low-pressure vapor passes through rubber tubing to a gas meter, then to an IMPCO IT-11M pressure reduction valve, which reduces pressure to 5" of water column. Vapor then is delivered to IMPCO CA125 air valve type downdraft carburetor (mixer).

Exhaust System:

Single pipe conventional.

Performance Data: #5

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	7.8
0-45	13.0

2) Braking

Speed (mph)	Stopping distance (ft.)
27	32
46	104

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	86.0
Driver #2	85.2

4) Noise Levels

Test mode	Microphone distance	dB (A)
30 WOT	50'	74.5
30 cruise	50'	59.5
Idle	10'	57.5

Emissions Data: #5

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.82	12	22
CO	1.00	1000	1000
NO	0.78	809	1004

Part. (gm/mile): 0.01

Fuel Economy: #5

169.0 miles/million Btu

6

GEORGIA INSTITUTE OF TECHNOLOGY

Entrant: #6

Class: I.C.E. (Gaseous Fuel)

Team Captain: Dr. Sam V. Shelton
School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Body and Chassis: 1970 Ford, 2-door sedan

Vehicle Weight: 4350 lbs.

Power Plant: I.C.E.

Fuel: Compressed Natural Gas

Fuel System:

Dual-fuel natural gas conversion kit (MFD. by Pneumerics, Inc.), retains gasoline fuel system. Fuel stored in three DOT 3AA 2265 cylinders in trunk. Two stage pressure reduction, 2265 P.S.I. to 135 P.S.I., then 135 P.S.I. to about 1/2 inch of water column. Fuel then enters a variable venturi mixer (diaphragm controlled), with an air metering valve to control the amount of natural gas reaching the engine by sensing the air demand of the engine.

Exhaust System: Conventional system with catalytic reactor added.

Emission Control:

1) Ignition timing set at 6° BTDC to reduce NO_x and HC.

2) Excess air in mixture to reduce CO.

Performance Data: #6

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	7.4
0-45	13.5
20-50	11.8

2) Braking

Speed (mph)	Stopping distance (ft.)
31	56
52	150

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	82.0
Driver #2	86.0

4) Noise Levels

Test mode	Microphone distance	dB (A)
30 WOT	50'	68.0
30 cruise	50'	61.0
Idle	10'	76.0

Emissions Data: #6

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	2.26	82	130
CO	1.66	1000	1000
NO	0.49	100	166

Part (gm/mile): 0.02

Fuel Economy: #6

107.0 miles/million Btu

SAN JOSE STATE COLLEGE

Entrant: #10

Class: I.C.E. (Gaseous Fuel)

Team Captain: Robin Saunders
982 South Second Street
San Jose, California 95112

Body and Chassis: 1970 Toyota Corolla

Vehicle Weight: 1942 lbs.

Power Plant: I.C.E., 73.3 C.I.D., 4-cylinder

Fuel: Liquefied Petroleum Gas

Fuel System:

Storage in pressurized tank. Fuel passes through pressure regulator (heated by engine coolant) where it is vaporized. Vapor passes through a heat exchanger, where it cools incoming air for the carburetor. Vapor continues to carburetor, where it is mixed with pre-cooled air.

Exhaust System:

Exhaust manifold reactor, followed by platinum-catalytic reactor.

Emission Control:

1) Exhaust manifold reactor (EMR), with air injection into exhaust ports. Maintains high temperature (1000°F) and increased residence time for oxidation of HC and CO.

2) Platinum catalytic muffler installed approximately three feet downstream from EMR. Additional air introduced at outlet of EMR to aid further reaction of HC and CO.

Performance Data: #10

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.8
0-45	13.8
20-50	13.2

2) Braking

Speed (mph)	Stopping distance (ft.)
28	32
52	139

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	79.8
Driver #2	78.0

4) Noise Levels

Test mode	Microphone distance	dB (A)
30 WOT	50'	69.5
30 cruise	50'	62.5
Idle	10'	56.5

Emissions Data: #10

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.44	23	20
CO	20.48	1000	4800
NO	0.71	155	100

Part. (gm/mile): 0.03

Fuel Economy: #10

205.0 miles/million Btu

STANFORD UNIVERSITY

Entrant: #11

Class: I.C.E. (Gaseous Fuel)

Team Captain: Robert L. Byer
Hansen Labs
Stanford University
Stanford, California 94301

Body and Chassis: 1971 Lincoln-Mercury Capri

Vehicle Weight: 2438 lbs.

Power Plant: I.C.E., 98 C.I.D., 4-cylinder

Fuel: Liquefied Petroleum Gas

Fuel System:

Storage in two 10-gallon LPG tanks at a pressure of 140 P.S.I. Metered by IMPCO BJ liquid-to-vapor convertor and carburetor.

Emission Control:

1) Water injection system - designed to reduce NO_x emissions. Introduced water spray at 1/12 fuel rate at idle to 1/6 fuel rate at 60 mph. Injection rate controlled by venturi vacuum and controlling needle valve. Water supplied to float bowl by gasoline fuel pump.

2) Thermal reactor installed to reduce HC emissions by oxidizing them at high temperature. Operating temperature was 800°C to 950°C core temperature.

3) Platinum catalytic reactor installed to control CO. Operating temperature of about 750°C. Also helps further oxidation of HC.

4) Ignition timing set at 13° BTDC without vacuum advance to control NO_x .

5) Air/fuel ratio set at 17.5/1 to optimize emissions rather than power.

Performance Data: #11

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	5.1
0-45	10.7
20-50	10.0

2) Braking

Speed (mph)	Stopping distance (ft.)
32	47
53	139

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	75.0
Driver #2	83.2

4) Noise Levels

Test mode	Microphone distance	dB (A)
30 WOT	50'	74.5
30 cruise	50'	62.0
Idle	10'	61.0

Emissions Data: #11

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.41	10	47
CO	1.00	1000	1000
NO	1.17	260	471

Part. (gm/mile): 0.01

Fuel Economy: #11

224.0 miles/million Btu

UNIVERSITY OF CALIFORNIA AT BERKELEY

Entrant: #12

Class: I.C.E. (Gaseous Fuel)

Team Captain: Floyd Sam
University of California
Dept. of Mechanical Engineering
Berkeley, California 94720

Body and Chassis: 1970 Plymouth Belvedere, 4-door sedan

Vehicle Weight: 3980 lbs.

Power Plant: I.C.E., 318 C.I.D., V-8 Configuration

Transmission: Stock automatic

Fuel: Liquefied Petroleum Gas (propane)

Fuel System:

Storage in pressure tanks of 34.6 gal. capacity at 100 to 120 P.S.I. Fuel from tanks pass through fuel lock and then to liquid-to-vapor converter and pressure regulator (IMPCO model E). Fuel exits at 1.5 inches of water column through a hose to an IMPCO model 225 propane carburetor.

Exhaust System:

Two manifolds (one for each cylinder bank) followed by catalytic reactors with balance line across pipes upstream of the reactors. Y-connection into a regular muffler. Exhaust gas recirculation via 3/4" copper tubing from below Y-connection.

Emission Control:

1) Exhaust gas recirculation - lowers peak combustion temperature, reducing NO_x emissions. Copper tubing (3/4") picks up exhaust below catalytic reactors and delivers it to the carburetor. Butterfly valve prevents flow during idle (prevents rough idle) and full throttle (prevents power loss).

2) Englehard PTX-5 catalytic reactors - reduce hydrocarbon and CO emissions by oxidation. Operating temperature of 800°F to 1400°F. Installed about 2 feet downstream of exhaust manifolds.

Other Modifications:

1) Heat risers to intake manifold blocked to help reduce peak combustion temperature.

2) Capacitive discharge ignition system installed to assure reliable ignition at leaner fuel mixtures.

Performance Data: #12

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.2
0-45	10.1
20-50	8.4

2) Braking

Speed (mph)	Stopping distance (ft.)
28	33
49	127

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	86.2
Driver #2	82.7

4) Noise Levels

Test mode	Microphone distance	dB (A)
30 WOT	50'	77.0
30 cruise	50'	63.0
Idle	10'	60.5

Emissions Data: #12

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.12	10	25
CO	1.00	1000	1000
NO	0.70	108	179

Part. (gm/mile): 0.01

Fuel Economy: #12

114.2 miles/million Btu

UNIVERSITY OF SOUTH FLORIDA

Entrant: #15

Class: I.C.E. (Gaseous Fuel)

Team Captain: Vernon Krutsinger
College of Engineering
University of South Florida
Tampa, Florida 33620

Body and Chassis: 1970 Chevrolet El Camino

Vehicle Weight: 4200 lbs.

Power Plant: I.C.E., 454 C.I.D. V-8

Transmission: 4-speed manual

Fuel: Liquefied Petroleum Gas (propane)

Fuel System:

Pressure tank in bed of vehicle. Fuel passes to filter-fuel lock, then to converter-pressure regulator. Vapor then is fed to a variable venturi 4-barrel carburetor.

Exhaust System: Standard

Modifications: Replaced 5.13:1 rear end with 2.56:1 to lower engine rpm at a given speed.

Performance Data: #15

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	3.5
0-45	7.2
20-50	4.5

2) Braking

Speed (mph)	Stopping distance (ft.)
31	45
56	134

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	78.0
Driver #2	81.0

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	77.5
30 Cruise	50'	65.5
Idle	10'	63.0

Emissions Data: #15

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	1.27	17	113
CO	1.00	1000	1000
NO	0.57	155	165

PART. (gm/mile): 0.09

Fuel Economy: #15

127.0 miles/million Btu

UNIVERSITY OF EVANSVILLE

Entrant: #16

Class: I.C.E. (Gaseous Fuel)

Team Captain: Miss Cheryl Williams
P.O. Box 329
Evansville, Indiana 4770;

Body and Chassis: 1969 Oldsmobile Cutlass

Vehicle Weight: 4011 lbs.

Power Plant: I.C.E., 350 C.I.D., V-8 configuration

Transmission: Factory Automatic

Fuel: Liquefied Petroleum Gas (propane)

Fuel System:

Storage in a double tank of about 35 gallons capacity. Fuel conducted through 1/4" hose to a filter fuel lock (Century model # STF-1614). Fuel then passes to Century model #M-5 converter, where it is reduced to about atmospheric pressure and vaporized. Engine coolant is used as a heat source for vaporization. Vapor passes to Century model #3-C-705 DTLE duplex carburetor, where it is metered and mixed with air.

Exhaust System: Single-pipe standard with catalytic converter added.

Modifications:

1) Gasoline tank removed.

2) Trunk sealed from passenger compartment.

3) Hot air risers in intake manifold blocked.

Performance Data: #16

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	5.2
0-45	9.0
20-50	7.6

2) Braking

Speed (mph)	Stopping distance (ft.)
27	46
47	100

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	106.2
Driver #2	96.2

3) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	69.5
30 Cruise	50'	63.0
Idle	10'	57.0

Emissions Data: #16

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.40	21	37
CO	10.02	2200	2500
NO	1.47	299	314

PART. (gm/mile): 0.01

Fuel Economy: #16

104.4 miles/million Btu

17

TUFTS UNIVERSITY

Entrant: #17

Class: I.C.E. (Gaseous)

Team Captain: Peter Talmage
105 Anderson Hall
Tufts University

Body and Chassis: 1970 General Motors Chevelle four-door sedan

Vehicle Weight: 3300 lbs.

Power Plant: I.C.E., 250 C.I.D., 6-cylinders

Fuel: Liquefied Petroleum Gas (propane)

Fuel System:

Storage tank in trunk. Fuel flows through LPG line to filter fuel lock, then to a Beam 400A pressure regulator-vaporizer. Propane vapor passes on to the Beam carburetor, where it is metered and mixed with air. Following the carburetor is a Kenics Corp. static mixing tube to insure good air-fuel mixing.

Exhaust System:

2 1/2" O.D. tubing used to replace original 1 3/4" pipe. Engelhard catalytic reactor installed about 5 feet downstream from manifold. A modified Kenics Corp. static mixing tube (4 ft. x 4 in. diameter) was employed as a combination muffler-reactor.

Emission Control:

1) Pressure equalizing line installed between the mouth of the carburetor and the regulator low-pressure diaphragm. To eliminate overly-rich mixture from fuel surge.

2) Air injection into exhaust ports by standard G.M. system helps oxidize HC and CO.

3) Platinum-catalytic exhaust reactor to aid oxidation of HC and CO.

4) Exhaust static mixing tube plated with CuO to act as second catalytic reactor.

5) Exhaust system insulated to maintain high temperature for oxidation reactions.

6) Exhaust gas recirculation system installed to reduce NO_x.

Other Modifications:

1) All moving parts balanced and engine brought up to blueprint specifications.

2) Valves and seats ground to 45°, and seating area increased to improve heat transfer to head.

3) Special bearings (Clevite 77's) installed.

4) High-efficiency Silko oil filter installed.

5) Capacitor discharge ignition system installed to improve spark characteristics.

6) Radiator core size increased by 100%

7) Transmission oil cooler and engine oil cooler installed.

8) Intake and exhaust manifold ports were internally smoothed to increase flow.

9) Rear doors, rear deck, and hood replaced with fiber glass replicas.

10) Gasoline tank removed.

11) Volkswagon seats installed.

12) Steel-belted radial tires and heavy duty shock absorbers installed.

13) Aerodynamic front end added.

Performance Data: #17

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	7.8
0-45	13.2
20-50	9.9

2) Braking

Speed (mph)	Stopping distance (ft.)
32	52
50	127

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	82.8
Driver #2	82.6

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	74.0
30 Cruise	50'	64.0
Idle	10'	62.5

Emissions Data: #17

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.28	24	55
CO	1.00	1000	1000
NO	0.61	165	154

PART. (gm/mile) 0.02

Fuel Economy: #17

162.5 miles/million Btu

WINNER-CLASS I (Gaseous Fuel)

Worcester Polytechnic Institute

Entrant: #18

Class: I.C.E. (Gaseous Fuel)

Team Captain: Edward W. Kaleskas
24 Brooks Street
Worcester, Massachusetts 01609

Body and Chassis: 1970 Chevy II Nova, 4-door sedan

Vehicle Weight: 2960 lbs.

Power Plant: I.C.E., 350 C.I.D. Chevrolet propane engine, factory equipped with high temperature valves and seats, and impact extruded pistons.

Transmission: Chevrolet turbohydramatic with kickdown linkage disconnected.

Fuel: Liquefied Petroleum Gas (propane)

Fuel System:

Storage in 35 gallon pressure tank located in trunk. Fuel flows through high pressure hose to the converter. In the converter, fuel is reduced in pressure and vaporized. Vapor then passes to Ensign variable venturi carburetor.

Exhaust System:

Standard single exhaust system, but with two Engelhard catalytic reactors at the exits of the exhaust manifolds.

Emission Control:

1) Catalytic exhaust reactors used to oxidize HC and CO.

2) Double head gaskets installed to lower compression ratio, thereby lowering flame temperature and reducing NO_x.

3) Ignition timing set at 6° BTDC and vacuum advance eliminated to reduce NO_x.

4) Lean air-fuel ratio (23/1) used to reduce NO_x by lowering flame temperature.

Performance Data: #18

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	5.6
0-45	8.6
20-50	5.2

2) Braking

Speed (mph)	Stopping distance (ft.)
29	35
53	127

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	75.0
Driver #2	76.8

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	78.0
30 cruise	50'	62.0
Idle	10'	67.5

Emissions Data: #18

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.24	10	20
CO	1.00	1000	1000
NO	0.55	100	100

Part. (gm/mile): 0.02

Fuel Economy: #18

111.2 miles/million Btu

BUFFALO STATE UNIVERSITY

Entrant: #19

Class: I.C.E. (Gaseous Fuel)

Team Captain: John Schifferle
Rm. 312 Upton Hall
Buffalo State University
1300 Elmwood Avenue
Buffalo, New York 14222

Body and Chassis: 1961 Austin-Healey Sprite, with modified body and frame.

Vehicle Weight: 1900 lbs.

Power Plant: I.C.E., 58 C.I.D., 4 cylinder Austin-Healey

Drive Train: 4-speed manual transmission, 3.7:1 rear end ratio

Fuel: Liquefied Petroleum Gas (propane)

Fuel System:

Storage in 8-gallon aluminum tank located in trunk. Fuel passes through pressure regulator and vaporizer to two Beam propane carburetors.

Exhaust System: Standard single-pipe and muffler

Modifications:

1) Additional frame members installed; roll bar added.

2) Collapsible steering column installed.

3) Engine parts trued and balanced, new head installed, and manifold ports polished.

4) 2 quart reservoir added to cooling system.

5) Body modified to increase trunk volume and improve appearance.

6) 2-ply radial tires installed.

Performance Data: #19

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.0
0-45	11.2
20-50	11.2

2) Braking

Speed (mph)	Stopping distance (ft.)
30	36
46	81

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	75.0
Driver #2	75.0

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	84.5
30 Cruise	50'	79.5
Idle	10'	76.5

Emissions Data: #19

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.33	20	73
CO	9.24	1000	1600
NO	0.80	428	1085

PART. (gm/mile) 0.10

Fuel Economy: #19

254.0 miles/million Btu

VILLANOVA UNIVERSITY

Entrant: #20

Class: I.C.E. (Gaseous Fuel)

Team Captain: M.J. Cafarella
c/o Mr. Bert Abrams
Norristown Auto Company, Inc.
Cooper Road and Main Street
Norristown, Pennsylvania

Body and Chassis: 1970 Ford Mustang, 2-door hardtop

Vehicle Weight: 3100 lbs.

Power Plant: I.C.E., 351 C.I.D., Ford V-8

Transmission: Ford cruisomatic

Fuel: Liquefied Petroleum Gas (propane)

Fuel System:

29.5 gallon storage tanks, IMPCO pressure regulator-vaporizer, IMPCO 4-barrel propane carburetor.

Exhaust System: Two Engelhard PTX-4 catalytic reactors added to standard system; one 12" below each manifold.

Emission Control:

1) Catalytic reactors added to oxidize HC and CO.

2) Exhaust gas recirculation system installed to reduce NO_x.

Performance Data: #20

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	5.0
0-45	12.4
20-50	No data

2) Braking

Speed (mph)	Stopping distance (ft.)
29	30
53	127

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	81.7
Driver #2	78.8

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	74.5
30 Cruise	50'	59.5
Idle	10'	58.0

Emisssions Data: #20

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.93	37	51
CO	2.72	1000	1000
NO	1.39	382	263

PART (gm/mile) 0.01

Fuel Economy: #20

136.2 miles/million Btu

SOUTHERN METHODIST UNIVERSITY

Entrant: #21

Class: I.C.E. (Gaseous Fuel)

Team Captain: James Tolbert
c/o Carlos W. Coon, Jr.
Institute of Technology
Southern Methodist University
Dallas, Texas 75222

Body and Chassis: 1970 Ford Mustang

Vehicle Weight: 3434 lbs.

Power Plant: I.C.E., 302 C.I.D., Ford V-8

Fuel: Liquefied Petroleum Gas

Fuel System:

Storage in pressurized tank located in trunk. Fuel passes to an Algas pressure regulator-vaporizer, and then to the Algas carburetor.

Exhaust System:

Dual exhaust system, with an Engelhard PTX catalytic reactor behind each manifold.

Emission Control:

1) Catalytic reactors aid oxidation of HC and CO.

2) Distributor Modulator System (manufactured by Ford) installed to eliminate vacuum spark advance at low speeds, thereby reducing NO_x emissions.

3) Ford thermactor exhaust system (air injection)installed to provide air for better oxidation of HC and CO.

4) Exhaust gas recirculation system installed to help reduce NO_x. Recirculated gases cooled in heat exchanger before entering carburetor.

Miscellaneous Modifications:

1) Rear end ratio changed from 3.03:1 to 2.76:1 for better fuel economy.

2) Stellite coated valves and seats installed in engine.

3) Air scoop provided for intake air.

4) Instruments installed: Propane Fuel Gauge
Water Temperature Gauge
Tachometer
Oil Pressure Gauge

Performance Data: #21

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	5.2
0-45	8.2
20-50	6.7

2) Braking

Speed (mph)	Stopping distance (ft.)
30	38
55	158

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	77.4
Driver #2	73.4

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	68.0
30 Cruise	50'	64.0
Idle	10'	61.0

Emissions Data: #21

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.62	16	57
CO	4.42	1000	3300
NO	2.56	291	339

PART. (gm/mile) 0.03

Fuel Economy: #21

147.2 miles/million Btu

UNIVERSITY OF WISCONSIN

Entrant: #22

Class: I.C.E. (Gaseous Fuel)

Team Captain: Bruce Peters, Dept. of Mechanical Engineering
University of Wisconsin
Madison, Wisconsin 53706

Body and Chassis: Opel GT

Vehicle Weight: 2109 lbs.

Power Plant: I.C.E.; 116 C.I.D., Opel 4-cylinder

Fuel: Liquefied Petroleum Gas (Propane)

Fuel System:

Storage in double tank located in rear or vehicle. Two-stage pressure reduction takes place in Ensign regulator-vaporizer. Vapor then passes to Ensign propane carburetor.

Exhaust System:

Standard Opel system with Engelhard PTX-5D catalytic reactor installed 18 inches below manifold.

Emission Control:

1) Catalytic reactor added to oxidize HC and CO.

2) Exhaust gas recirculation system installed to reduce NO_x.

3) Air-fuel ratio set lean at 22/1 to reduce CO and NO_x.

Miscellaneous Modifications:

1) Gasoline tank removed

2) Sheet metal bulkhead installed between passenger compartment

3) Heater fins milled off of intake manifold and radiation shield installed to provide cooler air-fuel mixture.

4) Valves and seats reground for greater width to increase heat transfer from valves to head.

Performance Data: #22

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.1
0-45	12.3
20-50	11.5

2) Braking

Speed (mph)	Stopping distance (ft.)
34	55
49	116

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	79.0
Driver #2	79.5

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	77.0
30 Cruise	50'	66.0
Idle	10'	58.0

Emissions Data: #22

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.62	369	87
CO	1.00	1000	1000
NO	1.39	470	657

PART. (gm/mile) 0.01

Fuel Economy: #22

269.0 miles/million Btu

ST. CLAIR COLLEGE OF APPLIED ARTS AND TECHNOLOGY

Entrant:	#23
Class	I.C.E. (Gaseous Fuel)
Team Captain:	Gene Durocher c/o Jerry Ducharme St. Clair College 2000 Talbot Road Windsor, Ontario 42 Canada
Body and Chassis:	1970 Dodge Coronet
Vehicle Weight:	3610 lbs.
Power Plant:	I.C.E.; 318 C.I.D. Chrysler V-8
Transmission:	Chrysler 3-speed torqueflite automatic
Fuel:	Liquefied Petroleum Gas (propane)
Fuel System:	Century propane conversion kit. Fuel tanks (18.5 imperial gallons) located in rear in vehicle. Fuel passes through fuelock to converter, where it is reduced in pressure and vaporized. Vapor then passes to propane carburetor.
Exhaust System:	Standard system modified to accept catalytic reactors

Emission Control:

1) Special emission control device added to reduce HC output during deceleration. Throttle plates held open during deceleration above 18 mph.

2) Two Engelhard PTX-6D catalytic reactors added to exhaust system (one below each manifold) to oxidize HC and CO.

3) Air injection system installed to provide oxygen for catalytic reactors.

4) Ignition timing set at 0° T.D.C. and vacuum spark advance eliminated. Centrifugal advance characteristic changed to reduce NO_x emissions.

5) Exhaust gas recirculation system installed to reduce NO_x .

6) Compression ratio lowered by using double head gaskets. This lowers peak temperature and, therefore, No_x .

Miscellaneous Modifications: Pistons polished, new rings and head installed.

Performance Data: #23

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	4.9
0-45	8.4
20-50	7.6

2) Braking

Speed (mph)	Stopping distance (ft.)
30	56
52	169

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	81.6
Driver #2	88.6

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	74.0
30 Cruise	50'	61.0
Idle	10'	59.5

Emissions Data: #23

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.12	24	37
CO	3.19	1000	1000
NO	1.00	301	299

PART. (gm/mile) 0.03

Fuel Economy: #23

132.3 miles/million Btu

24

WHITWORTH COLLEGE

Entrant:	#24
Class:	I.C.E. (Gaseous Fuel)
Team Captain:	George L. Borhauer Whitworth College Spokane, Washington 99218
Body and Chassis:	Ford Maverick Grabber
Vehicle Weight:	2597 lbs.
Power Plant	I.C.E.; 302 C.I.D., Ford V-8
Transmission:	Standard Mustang manual 3-speed
Fuel:	Liquefied Petroleum Gas (propane)

Fuel System:

Fuel stored in twin Manchester propane tanks with total capacity of 34 gallons. Fuel passes through converter, where it is reduced in pressure and vaporized. Vapor passes on to Century #3CG-705-DTLE carburetor where it is mixed with air.

Exhaust System: Dual exhaust, with catalytic reactor installed in each half.

Emission Control:

1) Engelhard PTX catalytic reactors installed to oxidize HD and CO.

2) Engine tuned on test stand for minimum NO_x emissions. Parameters not specified in original report.

Miscellaneous Modifications:

1) Gasoline pump removed.

2) Michelin radial-ply tires installed for lower rolling resistance.

3) Heavy-duty shock absorbers and extra leaf in rear springs installed.

Performance Data: #24

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	3.8
0-45	7.0
20-50	6.0

2) Braking

Speed (mph)	Stopping distance (ft.)
28	37
48	116

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	79.2
Driver #2	77.3

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	83.0
30 Cruise	50'	62.0
Idle	10'	62.5

Emissions Data: #24

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.53	61	43
CO	2.72	1000	1000
NO	2.22	288	340

PART. (gm/mile) 0.02

Fuel Economy: #24

161.0 miles/million Btu

UNIVERSITY OF CALIFORNIA AT BERKELEY

Entrant: #30

Class: I.C.E. (liquid fuel)

Team Captain: Peter D. Venturini
Thermal Systems Division
College of Engineering
University of California
Berkeley, California 94720

Body and Chassis: 1970 Plymouth Belvedere four-door sedan

Vehicle Weight: 3700 lbs.

Power Plant: I.C.E.; 318 C.I.D. Chrysler V-8

Drive Train: Torqueflight 3-speed automatic transmission; 2.76:1 rear end ratio

Fuel: Unleaded gasoline

Fuel System: Standard, except for carburetor modification to permit exhaust gas recirculation

Exhaust System:

Exhaust thermal reactors fastened directly to the cylinder heads. Dual pipe combines before entering catalytic reactor. Conventional muffler and pipe follow catalytic reactor.

Emission Control:

1) Exhaust thermal reactor built and installed in conjunction with air injection system to oxidize HC and CO. Reactor composed of an external steel shell, a layer of ceramic fiber insulation, and a steel core to protect insulation from erosion. Air injection synchronized with exhaust valve opening to improve mixing.

2) Exhaust gas recirculation system installed to reduce NO_x. Log type manifold used to distribute gases directly into intake manifold. Alternate entry provided in carburetor. Control provided to eliminate recycle during choked operation, idle, and full throttle.

3) Engelhard PTX6 catalytic reactor installed to further oxidize HC and CO. Reactor and lead-in pipe insulated to maintain high operating temperature.

Performance Data: #30

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	5.5
0-45	11.8
20-50	11.2

2) Braking

Speed (mph)	Stopping distance (ft.)
29	34
51	116

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	81.0
Driver #2	84.8

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	71.0
30 Cruise	50'	61.5
Idle	10'	68.5

Emissions Data: #30

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.70	13	No data
CO	25.23	13,500	No data
NO	0.78	100	No data

PART. (gm/mile) 0.07

Fuel Economy: #30

99.8 miles/million Btu

LOUISIANA STATE UNIVERSITY

Entrant: #31

Class: I.C.E. (Liquid Fuel)

Team Captain: Michael V. Wall
c/o Dean Pressburg
College of Engineering
Louisiana State University
Baton Rouge, Louisiana 70803

Body and Chassis: 1970 Pontiac Le Mans, 4-door sedan

Vehicle Weight: 4100 lbs.

Power Plant: I.C.E.; 400 C.I.D. Pontiac V-8

Transmission: Factory stock automatic

Fuel: Leaded gasoline

Fuel System:

Standard gasoline tank. Electric fuel pump located in gas tank. Standard fuel line leads to special carburetor developed by Ethyl Corporation. Carburetor employs a single high-velocity primary venturi to achieve improved fuel atomization. Two secondary venturis, normally closed, provide extra capacity for increased power demands. Fuel mixture automatically enriched during high engine load. Enrichment also provided during deceleration by means of a throttle bypass controlled by manifold vacuum.

Exhaust System:

Exhaust thermal reactors mounted on cylinder heads. Large diameter (up to 4") insulated pipes lead from reactors to a Y-connection. Downstream from the Y-connection, a particulate trap was installed.

Emission Control:

1) Special carburetor designed to improve air-fuel mixture preparation for low emissions. Better atomization allows leaner air-fuel to be used, which results in lower NO_x and CO emissions.

2) Exhaust reactors employed to oxidize HC and CO. Large diameter insulated pipes installed to increase exhaust residence time and temperature for further oxidation of HC and CO.

3) Inertial particulate trap used to collect particles in exhaust stream.

4) Ignition timing retarded 10° from stock setting at idle. Modified vacuum advance system provides two-stage advance as vacuum increases to reduce NO_x emissions.

5) Exhaust gas recirculation system installed to reduce NO_x emissions. Relatively cool gases taken from below Y-connection in exhaust system and passed through jacketed cooler using engine coolant for further temperature reduction. Recycle rate is controlled by intake manifold vacuum and speed sensing switches to provide proper recycle during various operating modes.

Performance Data: #31

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	4.7
0-45	7.2
20-50	5.2

2) Braking

Speed (mph)	Stopping distance (ft.)
29	44
50	119

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	78.2
Driver #2	79.4

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	87.0
30 Cruise	50'	66.0
Idle	10'	62.0

Emissions Data: #31

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	1.67	10	32
CO	7.55	1100	1000
NO	1.60	185	365

PART. (gm/mile) 0.09

Fuel Economy: #31

142.1 miles/million Btu

WORCESTER POLYTECHNIC INSTITUTE

Entrant:	#32
Class:	I.C.E. (liquid fuel)
Team Captain:	Robert Guertin c/o Mechanical Engineering Department Worcester Polytechnic Institute Worcester, Massachusetts 01609
Body and Chassis:	1970 Saab 99E
Vehicle Weight:	2500 lbs.
Power Plant:	I.C.E.; 113 C.I.D. modified Triumph 4-cylinder engine
Fuel:	Unleaded gasoline
Fuel System:	Standard Saab fuel system, except for modification of the Bosch electronic fuel injection system.
Exhaust System:	Exhaust manifold thermal reactor mounted on cylinder head. Exhaust pipe carries gases to a platinum catalytic reactor, then out through a conventional muffler.

Emission Control:

1) Engine displacement increased from 104 C.I. to 113 C.I. Compression ratio lowered from 9:1 to 8:1 by installing deep dish pistons. These modifications lowered peak temperatures, thereby reducing NO_x emission.

2) New injectors and a new computer installed in fuel injection system to accomodate engine modifications and provide a richer air-fuel ratio in an effort to reduce NO_x.

3) Exhaust thermal reactor (designed by DuPont) installed in conjunction with synchronized air injection system to oxidize HC and CO.

4) Catalytic reactor employed to further oxidition of HC and CO.

5) Ignition timing retarded from standard to reduce NO_x by lowering peak combustion temperature.

Performance Data: #32

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	5.0
0-45	10.0
20-50	8.2

2) Braking

Speed (mph)	Stopping distance (ft.)
26.5	32
52.0	126

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	76.3
Driver #2	82.4

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	74.5
30 Cruise	50'	69.0
Idle	10'	59.5

Emissions Data: #32

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.87	10	36
CO	14.63	1000	2900
NO	0.50	491	528

PART. (gm/mile) 0.11

Fuel Economy: #32

175.2 miles/million Btu

WORCESTER POLYTECHNIC INSTITUTE

Entrant:	#33
Class:	I.C.E. (Liquid Fuel)
Team Captain:	Walter V. Thompson c/o Prof. R.R. Borden C.A.C.R. Committee Worcester Polytechnic Institute Worcester, Massachusetts 01609
Body and Chassis:	1970 Ford Mustang
Vehicle Weight:	3000 lbs.
Power Plant:	I.C.E.; modified 302 C.I.D. Ford V-8
Drive Train:	Ford C-4 three-speed automatic transmission, 3.08:1 rear axle ratio
Fuel:	Leaded Gasoline
Fuel System:	Standard tank and lines. Carburetion replaced by dual Volkswagon fuel injection system.
Exhaust System:	Standard manifolds. Poppet-type flow control valve installed below Y-connection. Arvin slant-bed catalytic reactor installed, followed by regular muffler. Particle agglomerator and final filter added below muffler.

Emission Control:

1) Fuel injection installed to allow very lean (18:1) air-fuel ratio to be used. This helps reduce NO_x, and provides excess oxygen for reaction with HC and CO in the exhaust system.

2) Compression ratio lowered from 9.5:1 to 7.3:1 to lower peak combustion temperature and reduce NO_x.

3) Ignition timing retarded 5° from stock to help reduce NO_x. Timing set at 11° BTDC.

4) Vehicle weight reduced by 500 lbs. to improve fuel economy and lower total emissions. Steel-belted radial tires installed to lower rolling resistance.

5) Catalytic reactor installed in exhaust system to oxidize HC and CO.

6) Particle agglomerator (inertial type) installed to increase particle size, and a final filter added to remove the particles. Extra pipe also added to cool exhaust before it reaches the agglomerator.

7) Vapor collection dome added to gas tank, and charcoal filled cannister installed to control evaporative HC emissions. Cannister is purged by PCV and air into the air cleaner intake.

Performance Data: #33

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	7.5
0-45	15.4
20-50	14.4

2) Braking

Speed (mph)	Stopping distance (ft.)
30	41
54	145

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	78.2
Driver #2	77.2

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	71.0
30 Cruise	50'	62.0
Idle	10'	59.0

Emissions Data: #33

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	2.10	57	58
CO	11.67	9600	1200
NO	1.11	326	234

PART. (gm/mile) 0.04

Fuel Economy: #33

128.5 miles/million Btu

UNIVERSITY OF MICHIGAN

Entrant: #34

Class: I.C.E. (Liquid Fuel)

Team Captain: David A. Olds
321 Auto Lab
University of Michigan
Ann Arbor, Michigan 48105

Body and Chassis: 1970 Volkswagen square back sedan

Vehicle Weight: 2500 lbs.

Power Plant: I.C.E.; 97.6 C.I.D. Volkswagen, 4-cylinder engine

Fuel: Unleaded gasoline

Fuel System: Factory stock, with Bosch electronic fuel injection system.

Exhaust System: Standard manifold. Two Engelhard platinum catalytic reactors installed in series, followed by a conventional muffler.

Emission Control:

1) Catalytic reactors installed to oxidize HC and CO.

2) Variable air-fuel ratio control accomplished by inserting a variable resistance in the manifold pressure transducer circuit, which controls the discharge duration of the fuel injectors. Slightly lean ratio used.

3) Water injection into the air-fuel mixture employed to reduce NO_x. Water injected on the inside of the air cleaner cowling by two injectors which are activated separately at two throttle openings. One is activated just above idle, the other at about half throttle.

4) Air injection at the exhaust ports installed to provide oxygen for reaction with HC and CO. Exhaust system wrapped with insulating tape to maintain high temperature and aid the oxidation process.

5) Temperature-sensitive vacuum advance shutoff valve provide additional spark retardation during engine warm-up. This results in hotter exhaust and faster reactor warm-up. One of the water injectors is also shut off during warm-up for the same reason.

Performance Data: #34

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	7.0
0-45	13.2
20-50	14.3

2) Braking

Speed (mph)	Stopping distance (ft.)
30	41
52	148

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	76.6
Driver #2	76.4

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	77.0
30 Cruise	50'	67.0
Idle	10'	63.5

Emissions Data: #34

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.67	13	24
CO	4.91	1000	1900
NO	1.41	406	314

PART. (gm/mile) 0.22

Fuel Economy: #34

228.0 miles/million Btu

35

UNIVERSITY OF MICHIGAN

Entrant: #35

Class: I.C.E. (Liquid Fuel)

Team Captain: Richard Waggoner
321 Auto Lab
University of Michigan
Ann Arbor, Michigan 48105

Body and Chassis: 1970 General Motors Chevelle 4-door hardtop

Vehcile Weight: 3800 lbs.

Power Plant: I.C.E.; 350 C.I.D. Chevrolet V-8

Fuel: Unleaded gasoline

Fuel System: Conventional system for gasoline operation

Exhaust System: Regular manifolds, One Engelhard platinum catalytic reactor installed just downstream from each cylinder bank. Pipe joins in Y-connection, where air is injected, then continues to two more Engelhard reactors connected in parallel. Conventional muffler follows reactors.

Emission Control:

1) First set of catalytic reactors installed to reduce NO_x by converting NO_x and CO to N_2 and CO_2.

2) Second set of reactors, in conjunction with air injection, designed to oxidize HC and CO.

Performance Data: #35

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	4.6
0-45	8.1
20-50	6.7

2) Braking

Speed (mph)	Stopping distance (ft.)
26	32
48	127

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	78.1
Driver #2	80.3

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	89.0
30 Cruise	50'	65.5
Idle	10'	63.5

Emissions Data: #35

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	1.38	27	48
CO	25.70	1000	1000
NO	1.06	233	970

PART. (gm/mile) 0.15

Fuel Economy: #35

126.4 miles/million Btu

OVERALL WINNER

Wayne State University

Entrant: #36

Class: I.C.E. (Liquid Fuel)

Team Captain: Richard Jeryan
18261 Forrer
Detroit, Michigan 48235

Body and Chassis: 1971 Ford Capri

Vehicle Weight: 2300 lbs. (approximately)

Power Plant: I.C.E.; 302 C.I.D. Ford V-8

Drive Train: Ford C-4 automatic transmission, 2.33:1 rear axle ratio

Fuel: Unleaded gasoline

Fuel System:

Polyethylene fuel tank (18 gal. capacity) with an in-tank electric fuel pump installed. Insulated fuel lines led to modified carburetor. Mechanical fuel pump retained for emergency use.

Exhaust System:

Conventional manifolds. Two Engelhard PTX-5 catalytic reactors installed below each manifold. Air introduced below the first set (before the second set) of reactors. Dual pipe combines, then enters conventional muffler.

Emission Control:

1) Vehicle weight reduced to lower power demand, thereby lowering total emissions, improving fuel economy and performance.

2) Low valve overlap(11°) camshaft installed to reduce hot residual gases in cylinder and allow more cold exhaust gas recycle. This lowers peak combustion temperature which reduces NO_x emissions.

3) Combustion chambers contoured to reduce "dead" (non-burning) volumes, which reduces HC emissions.

4) Projections on the head and piston were removed to eliminate hot spots, thereby reducing NO_x formation.

5) Time constant of Vacuum spark advance system increased to lower transient emissions.

6) Exhaust gas recirculation system employed to lower NO_x emissions. Vacuum override system connected to spark advance line prevents recycle when spark vacuum is below 4 or above 20 inches of mercury.

7) Air-fuel ratio stabilized between 14.5:1 and 15:1 by carburetor air and fuel temperature control features. Air temperature controlled by temperature-sensitive valve which mixes high and low temperature inlet air. Fuel lines insulated, and carburetor insulated from engine heat. Close air-fuel ratio control allows catalytic exhaust reactors to function at maximum efficiency.

8) Dual power valve system added to carburetor to reduce bore-to-bore imbalance, providing additional control of air-fuel ratio.

9) PCV valve replaced by .076 inch orifice to reduce effect of varying crankcase flow rate on air-fuel ratio.

10) First set of catalytic reactors employed to reduce NO_x.

11) Second set of reactors, in conjunction with air injection, installed to oxidize HC and CO.

Miscellaneous Modifications

1) Hardened valve seats installed.

2) Oil pan and pump, front end belt drives modified to facilitate engine installation.

3) Extra-capacity radiator installed, and extra air ports cut in front sheet metal.

Performance Data: #36

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	3.6
0-45	5.2
20-50	4.2

2) Braking

Speed (mph)	Stopping distance (ft.)
35	59
53	124

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	69.4
Driver #2	68.6

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	73.0
30 cruise	50'	63.0
Idle	10'	59.0

Emissions Data: #36

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	1.21	10	16
CO	13.76	1000	1000
NO	0.70	100	118

Part. (gm/mile): 0.04

Fuel Economy: #36

196.3 miles/million Btu

37

UNIVERSITY OF WISCONSIN

Entrant: #37

Class: I.C.E. (Liquid Fuel)

Team Captain: Harrison Sigworth
c/o Mechanical Engineering Department
University of Wisconsin
Madison, Wisconsin 53706

Body and Chassis: 1970 Lotus Europa

Vehicle Weight: 1760 lbs.

Power Plant: I.C.E.; Renault R-16 4-cylinder engine

Fuel Unleaded gasoline

Fuel System: Conventional Lotus System

Exhaust System:

Air injected at three of the four exhaust ports. Part of the exhaust gas from the fourth port is recirculated to the intake manifold. Conventional exhaust manifold is followed by an Engelhard platinum catalytic reactor, a thermal reactor and a resonator, in that order.

Emission Control:

1) Factory emission control features include special retarded spark timing, blowby emission control, special top piston rings to minimize quench volume, and special carburetion and intake manifold for lean operation.

2) Exhaust port air injection installed to provide oxygen for reaction with HC and CO in exhaust system. Antibackfire valve routes air to pipe just above catalytic reactor during severe deceleration. Air injected at three exhaust ports.

3) Exhaust gas recirculation employed to lower NO_x emissions. Exhaust from port without air injection is routed through a control orifice and a distribution manifold to the intake manifold. Recirculation rate up to 25% of intake charge.

4) Catalytic reactor installed to oxidize HC and CO.

5) Thermal reactor designed, built, and installed by entrant team to further oxidize HC and CO. Reactor is an insulated can designed to give increased residence time at high temperature.

6) Spark timing further retarded to reduce NO_x . A vacuum switch shuts off all vacuum advance at intake manifold pressures above 9 psia.

7) Evaporative emission control system from a Ford Maverick installed. System consists of a charcoal cannister, gas tank air bleed valve, and a vapor-liquid separator and expansion chamber. Fuel vapors are routed from the cannister to the engine intake.

Performance Data: #37

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	5.5
0-45	9.6
20-44	7.0

2) Braking

Speed (mph)	Stopping distance (ft.)
34	50
55	136

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	78.3
Driver #2	79.2

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	72.5
30 Cruise	50'	63.0
Idle	10'	60.5

Emissions Data: #37

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	1.56	13	17
CO	3.84	2000	1000
NO	0.84	190	396

PART. (gm/mile) 0.10

Fuel Economy: #37

288.0 miles/million Btu

WINNER-CLASS I (Liquid Fuel)

Stanford University

Entrant: 41

Class: I.C.E. (liquid fuel)

Team Captain: Dana G. Andrews
c/o Robert Byer
Hansen Labs
Stanford University
Stanford, California 94301

Body and Chassis: 1970 American Motors Gremlin

Vehicle Weight: 2569 lbs.

Power Plant: I.C.E.; 232 C.I.D. American Motors 6-cylinder engine.

Drive Train: Three-speed manual transmission, 3.08:1 rear axle ratio

Fuel: Methanol (Methyl Alcohol)

Fuel System:

Standard fuel tank retained. Conelec electric fuel pump installed, but malfunction necessitated use of lower capacity stock fuel pump. Zenith model 32 NDIX two-barrel carburetor, mixture heater, and water heated intake manifold installed.

Exhaust System:

Standard system augmented with an Engelhard Diesel Exhaust Purifier (catalytic reactor). Exhaust gas recirculation system installed.

Emission Control:

1) Lean air-fuel ratio (8.5:1 at low speeds to 7.5:1 at full throttle) used to reduce HC, CO, and NO_x. Stoichiometric ratio is 6.5:1.

2) Heat exchanger (heated by engine coolant) installed in adapter plate between carburetor and intake manifold. In conjunction with water-heated manifold, this provides better fuel vaporization and distribution, which results in lower HC, CO, and NO_x.

3) Catalytic reactor employed to oxidize HC and CO with excess air provided by lean operation.

4) Exhaust gas from exhaust manifold recirculated into intake manifold to lower NO_x. Hot gases also help vaporize fuel.

Performance Data: #41

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.0
0-45	11.6
20-50	10.2

2) Braking

Speed (mph)	Stopping Distance (ft.)
29	40
50	122

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	83.8
Driver #2	81.0

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	70.5
30 cruise	50'	59.0
Idle	10'	52.0

Emissions Data: #41

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.42	23	44
CO	4.68	1000	2300
NO	0.86	279	116

Part. (gm/mile): 0.02

Fuel Economy: #41

171.0 miles/million Btu

UNIVERSITY OF CALIFORNIA IN LOS ANGELES

Entrant: #42

Class: I.C.E. (Liquid Fuel)

Team Captain: Roberta Nichols
1723 Hickory Avenue
Torrance, California 90503

Body and Chassis: 1965 Ford Mustang

Vehicle Weight: 2800 lbs.

Power Plant: Diesel-I.C.E.; 138 C.I.D. Daihatsu light truck engine (imported from Japan). Four cylinders, in-line, with swirl-type combustion chambers.

Drive Train: Ford 4-speed manual transmission, 3.23:1 rear axle ratio

Fuel: Diesel Oil

Fuel System:

Bosch "A" type solid fuel injection with throttle type nozzles in individual precombustion chambers. Pneumatic governor system (stock with engine) allows constant-speed operation, regardless of load.

Exhaust System:

Conventional muffler removed. Airesearch model TO-4 Turbocharger (driven by exhaust pressure) installed. Remainder of conventional piping retained.

Emission Control:

Turbocharger added to provide excess air for more complete combustion, reducing HC and CO emissions. Pneumatic governor atmospheric balance line modified to compensate for increased pressure in intake manifold.

Performance Data: #42

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	10.1
0-40	17.1
0-45	21.8
20-45	16.0

2) Braking

Speed (mph)	Stopping distance (ft.)
28	47
48	136

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	94.0
Driver #2	86.2

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	78.0
30 Cruise	50'	66.0
Idle	10'	63.0

Emissions Data: #42

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	1.60	141	66
CO	3.40	1000	1000
NO	2.30	472	480

PART. (gm/mile) 0.16

Fuel Economy: #42

260.0 miles/million Btu

51

UNIVERSITY OF ARIZONA

Entrant: #51

Class: I.C.E. (Gaseous Fuel)

Team Captain: Mark Carnes
c/o Electrical Engineering Department
University of Arizona
Tucson, Arizona 85721

Body and Chassis: 1970 Plymouth Duster

Vehicle Weight: 3500 lbs.

Power Plant: I.C.E.; 318 C.I.D. Plymouth V-8

Transmission: Three-speed manual

Fuel: "Fuel Gas," a mixture of methane (CH_4) and hydrogen (H_2). A mixture of 90% methane and 10% hydrogen was used in the race events.

Fuel System:

Liquid methane stored in 19-gallon cryogenic tank. Compressed hydrogen stored in tank of 220 cubic feet capacity. Conventional regulators of the type used on welding equipment were used to set the output pressure of each tank. Each gas line then passed through an electrically - controlled valve. The two lines combined in a T - connection, and a single line carrying the methane-hydrogen mixture passed through another valve and entered in IMPCO regulator. Vapor from the regulator entered the carburetor at a pressure between 0" and 6" of water column.

Exhaust System: Single-pipe conventional system.

Emission Control:

1) Output pressure of second-stage fuel regulator empirically set at optimum for lowest combined HC and NO emissions. Optimum setting at about 1/2" of water column.

2) Ignition timing set at 0° T.D.C. to provide optimum balance between HC and NO_x.

3) Electronic fuel cut-off provided during deceleration to lower HC emissions.

Performance Data: #51

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	4.3
0-45	7.4
20-50	6.0

2) Braking

Speed (mph)	Stopping distance (ft.)
26	32
52	155

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	78.0
Driver #2	80.2

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	78.0
30 Cruise	50'	62.0
Idle	10'	63.5

Emissions Data: #51

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.94	28	76
CO	1.43	1000	1000
NO	0.84	168	347

PART. (gm/mile) 0.01

Fuel Economy: #51

165.0 miles/million Btu

PUTNAM CITY WEST HIGH SCHOOL

Entrant: #52

Class: I.C.E. (Gaseous Fuel)

Team Captain: Alan T. Axworthy
Putnam City West High School
8000 N. W. 23rd Street
Oklahoma City, Oklahoma 73127

Body and Chassis: Opel GT

Vehicle Weight: 2300 lbs.

Power Plant: I.C.E.; 115 C.I.D. Opel 4-cylinder engine.

Transmission: Four-speed manual

Fuel: Compressed Natural Gas or Liquefied Petroleum Gas. Vehicle can operate on either fuel.

Fuel System:

CNG stored in four 1500 cu.in. capacity tanks at 1000 p.s.i. maximum pressure. Tank pressure reduced to 150 p.s.i. by single-stage regulator, then further reduced to 2" of water column in a two-stage regulator. Vapor from regulator passes to carburetor.

LNG stored in 14 water gallon capacity propane tank. Fuel passes to a two-stage vaporizer-regulator, then to carburetor.

Solenoid valves control choice of fuel.

Exhaust System:

Conventional manifold followed by an Engelhard PTX catalytic reactor and regular muffler.

Emission Control:

1) air-fuel ratios set very lean to reduce HC and CO emissions.

2) Catalytic reactor employed to oxidize HC and CO.

3) Air injection system installed to provide excess oxygen for catalytic reactor.

4) Exhaust gas recirculation system installed to reduce NO_x emissions.

5) Cold intake manifold used to reduce peak combustion temperature, thus reducing NO_x .

6) Vacuum spark advance eliminated to help reduce NO_x formation. Centrifugal advance retained.

Performance Data: #52

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.3
0-40	10.3
20-50	15.1

2) Braking

Speed (mph)	Stopping distance (ft.)
26	47
50	139

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	81.4
Driver #2	82.4

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	74.0
30 Cruise	50'	65.5
Idle	10'	57.0

Emissions Data: #52

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	1.43	128	727
CO	1.00	1000	1000
NO	1.77	780	294

PART. (gm/mile) 0.02

Fuel Economy: #52

216.0 miles/million Btu

61

GEORGIA INSTITUTE OF TECHNOLOGY

Entrant: #61

Class: Electric

Team Captain: Dave Robinson
c/o Dr. Ronald Larson
School of Electrical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Body: Fabricated steel tubing roll cage, with sheet metal panels.

Chassis: 1967 Volkswagen Fastback

Vehicle Weight: 2900 lbs.

Power Plant: Series would D.C. electric motor - develops 25.7 H.P. at 5000 RPM and 120 volts.

Drive Train:

Motor mounted on cantilever construction above and forward of standard VW bell housing. Power transmitted to the clutch assembly by 2:1 reduction timing belt drive. VW transaxle retained in drive train.

Energy Storage:

Replaceable battery pack - 24 six volt Prestolite golf cart batteries with total energy storage capacity of about 26 Kilowatt-hours. Batteries arranged in removable trays of 3 each to facilitate quick change-over to fresh batteries. Recharging accomplished at off-board stationary or mobile facilities.

Energy Control System:

Full battery voltage (144v) applied in pulses to drive motor. Voltage pulses gated through dual SCR network by multivibrator circuit controlling pulse width from zero to 100% of vibrator pulsing period.

Miscellaneous Features:

Accessory power supplies by two 6v Prestolite golf cart batteries to operate lights, windshield wipers, etc.

Instrumentation provided to monitor:

1) Battery temperature
2) Motor temperature
3) Motor voltage
4) Motor current
5) Auxiliary battery voltage
6) Ampere hours
7) Battery electrolytic resistivity

Performance Data: #61

1) Acceleration

Speed range (mph)	Time (sec.)
0-25	22.1

2) Braking

Speed (mph)	Stopping distance (ft.)
30	55

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	105.0
Driver #2	106.8

4) Noise Levels

Not tested

Emissions Data: N/A

Fuel Economy: No data

IONA COLLEGE

Entrant: #64

Class: Electric

Team Captain: Carl Borello
c/o Paul LaRusso
Iona College
North Avenue
New Rochelle, New York

Body and Chassis: 1962 Volkswagen "Beetle"

Vehicle Weight: 2300 lbs.

Power Plant: Eight 2 horsepower D.C. Electric motors, arranged such that two or four motors at a time transmit power to the driveshaft.

Drive Train: Three successive drive ratios employed to start vehicle motion.

1) First set of two motors drive at an 8:1 ratio. Other motors idle on the drive shaft.
2) First set mechanically disengages, second set (four motors) drives at 4:1 ratio. Two remaining motors idle on shaft.
3) Second set mechanically disengages, third set (two motors) drives at 1.14:1 ratio for cruising.

Maximum motor speed for all motors is 4000 r.p.m. Each motor powered by its own 24-volt battery.

Performance Data: Not tested

Emissions Data: N/A

Fuel Economy: No data

WINNER-CLASS IV

Cornell University

Entrant: #65

Class: Electric

Team Captain: Mark Hoffman
224 Phillips Hall
Cornell University
Ithaca, New York 14850

Body and Chassis: American Motors Hornet

Vehicle Weight: 5311 lbs.

Power Plant: Electric motor, D.C. four pole configuration. 20 H.P. continuous rating, with overlaod capacity to 120 H.P.

Drive Train: Standard Hornet 3-speed manual transmission, driveshaft

Energy Storage:

Battery pack consisting of 24 six-volt Electric Fuel Propulsion lead-cobalt (variation of lead-acid) batteries. 34 kilowatt-hour capacity.

Power Control:

"3 in 1" dual chopper: circuitry which pulses battery voltage to the motor. Even harmonics of chopper frequency are cancelled, reducing A.C. component and, therefore, heat losses in the motor. Pulse width and frequency are modulated to control motor speed.

Chopper also functions as regenerative braking control. Motor acts as a generator when accelerator is released. Pressing brake pedal brings regenerative braking to its maximum, and actuates the hydraulic brakes. Power generated by this process is returned to batteries.

Due to last-minute problems, the 3-in-1 dual chopper was not used during the Race. A ten-step series-paralled contactor controller was used as a substitute. This controller provided levels of 12, 24, 36, 72, 108, and 144 volts to the motor, with a motor field weakening step after each of the last four voltage levels.

Recharging Scheme:

On-board charger can accept 208 to 240 volts single-phase A.C., three-phase A.C., or D.C. and can supply up to 500 amps to the battery pack. Charger regulation includes voltage, current, temperature, and gassing controls.

Performance Data: #65

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	8.5
0-45	18.4
20-40	14.0

2) Braking

Speed (mph)	Stopping distance (ft.)
30	61
49	186

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	89.8
Driver #2	87.8

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	62.0
30 cruise	50'	61.0
Idle	10'	Not applicable

Emissions Data: #65

Not applicable.

Fuel Economy: #65

189.8 miles/million Btu*

Electrical Efficiency: #65

1.85 miles/kilowatt-hour

*includes correction for power plant efficiency of 35%

STEVENS INSTITUTE OF TECHNOLOGY

Entrant: #66

Class: Electric

Team Captain: Henry Van Handle
c/o American Smelting & Refining
Central Research Laboratories
South Plainfield, New Jersey 07080

Body and Chassis: Built by the Kalmar Co. of Sweden as a delivery van with gasoline engine. Modified by Electric Fuel Propulsion, Inc. for battery power. Body of Fiberglass.

Vehicle Weight: 4200 lbs.

Power Plant: D.C. electric motor, 15 H.P., four-pole, series traction type.

Drive Train:

Power transmitted to two separate rear axles by belt drive system with continuously variable ratio drive. Each of the two pulleys on motor shaft coupled to a driven pulley on an axle. Pulley pitch diameter (drive ratio) controlled by flyball governor.

Energy Storage:

Twenty 6 volt batteries, arranged in four banks of 30 volts each. Batteries are tri-polar, lead-cobalt (a type of lead-acid) made by Electric Fuel Propulsion, Inc. The battery pack can store 200 ampere hours at the two hour rate, or 290 ampere hours at the twenty hour rate. Total battery weight is about 2000 lbs.

Power Control:

Hartman switching control which provides seven discrete power levels, plus an "off" position. Control actuated by foot pedal.

1) All banks in parallel, 30 volts applied to motor through series resistor to limit current surge to get vehicle started.
2) Same as above but without resistor.
3) Same as 2), but with shunt resistor on field winding for field weakening.
4) 60 volts applied to motor, all resistance out of circuit.
5) Same as 4), but with field weakening.
6) 120 volts to motor, all resistance out.
7) Same as 6), but with field weakening.

Recharging Scheme:

On-board charger uses 3-phase bridge network of 3 SCR's and 3 diodes. Designed for power input of 240 volt, 3-phase, 150 amp service, but can also accept 220 volt, single-phase service. Feedback loop in charger control circuit limits voltage impressed on battery pack to 150 volts. Batteries can be charged to 80% of capacity in 45 minutes, or 95% of capacity in 90 minutes.

Performance Data: #66

1) Acceleration

Speed range (mph)	Time (sec.)
0-20	11.2
0-30	17.0
0-36	29.2

2) Braking

Speed (mph)	Stopping distance (ft.)
24	30

3) Urban Driving Cycle

	Best Time (sec.)
Driver #1	95.0
Driver #2	95.0

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	62.0
30 Cruise	50'	61.0
Idle	10'	Background

Emissions Data: N/A

Fuel Economy:

146.4 mile/million Btu*

Electrical Efficiency:

1.43 miles/kilowatt-hour

* includes correction for power plant efficiency of 35%.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Entrant:	#70
Class:	Electric-I.C.E. Hybrid
Team Captain:	William Carson Room 13-3005 M.I.T. Cambridge, Mass. 02139
Body and Chassis:	1968 Chevrolet Corvair
Power Plant:	Shunt wound D.C. Electric traction motor. 20 H.P. rated, 100 H.P. peak output.
Drive Train:	Corvair 4-speed manual transmission and axle assembly.
Batteries:	Fourteen lead-acid batteries with total rated capacity of 90 ampere-hours at 168 volts.

Power Control:

Power controller uses a 2 phase SCR chopper at low motor speeds and shunt field control at high motor speeds. The chopper pulses battery voltage through an inductor to the motor. Controller also allows motor to be used as a generator for partial recharging of batteries during deceleration or downhill rolling (regenerative braking). Controller includes current limiting, voltage limiting, and motor speed limiting circuits, as well as logic circuitry for automatic selection of operating mode. Adjustable controller current and motor speed limits on dashboard.

Recharging Scheme:

Batteries can be recharged from an external power supply, or by the on-board gasoline engine-alternator assembly. The power controller functions as a battery charger to rectify alternating current. Voltage and current limits for recharging may be set on the dashboard. External power supply may be 208 volt or 240 volt, single phase or three phase A.C. For on-board recharging, the gasoline engine is automatically turned on and off by a controller which measures charge state of the batteries, or by manual overrides. Engine may be left on to complete charging cycle, even after removal of ignition key. Automatic turn off and failure lights are provided in case of engine failure.

Engine:	4-cylinder Austin-Healey
Emission Control:	Engine operates only at constant speed and full throttle--avoids high emissions during acceleration and deceleration. Lean fuel-air mixture to reduce CO and HC.

Compression ratio lowered to 6.9:1 to lower flame temperature and reduce NO_x.

Water injection system installed to reduce NO_x.

Miscellaneous Features:

Freon cooling of batteries when gasoline engine is operating.

Battery pack electrically floated with respect to car ground, with siren warning in case of accidental grounding.

Fluid cooling of electronic controls.

Performance Data: Not tested

Emissions Data: #70

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	3.82*	no data	no data
CO	82.73*	no data	no data
NO	6.28*	no data	no data

Part. (gm/mile): No data

Fuel Economy: #70

No data

* These values obtained for first six cycles out of a total of nine. Engine automatically shut off after sixth cycle, and vehicle completed test in pure electric mode.

CO-WINNER-CLASS V

Worcester Polytechnic Institute

Entrant: #71

Class: Electric-I.C.E. Hybrid

Team Captain: Steven Clarke
Mechanical Engineering Department
Worcester Polytechnic Institute
Worcester, Mass. 01609

Body and Chassis: 1970 American Motors Gremlin

Vehicle Weight: 4740 lbs.

Power Plant: General Electric type BY401, 25 H.P., series wound direct current traction electric motor. Battery pack rated at 200 amp-hours at 20 hour rate.

Drive Train: Jeep drive shaft, heavy duty 5:1 ratio differential

Batteries:

Twenty Exide type 3EC-19, 6 volt lead-acid batteries, connected in series for 120-volt power. Battery pack rated at 200 amp-hours at 20 hour rate.

Power Control:

Modified General Electric model 300 SCR controller. Full battery voltage applied to motor in pulses. Speed and torque controlled by varying pulse frequency through foot-pedal potentiometer. Pulsing circuit by-pass provided for top speed operation.

Recharging Scheme:

Batteries charged with current supplied by a General Electric tri-clad brushless synchronous generator. The generator is driven by an internal combustion engine. Control curcuits allow the batteries to accept charge during low-power vehicle operation, or deliver power at greater loads. The generator can provide 25 KVA of 3-phase A.C. power, which is rectified to provide D.C.

Engine:

Jeep Dauntless V-6 I.C.E.

Emission Control:

1) Englehard catalytic reactors installed just downstream of exhaust manifolds to oxidize HC and CO.

2) Air injection on exhaust manifolds to provide oxygen for reactors.

3) Exhaust gas recirculation to lower NO_x emissions.

Vehicle Modification:

1) Suspension stiffened by installing coil and leaf springs from an A.M. ambassador, and adding Booster coils to the shock absorbers.

2) Goodyear 15 inch radial tires and wheels to match installed.

3) Rear seat removed to make room for battery pack.

4) Ten-inch brake drums installed.

5) Hood Modified (raised) to provide clearance for engine components.

6) Instruments include tachometer, speedoment, odometer, water temperature gauge, oil pressure gauge, alternator voltmeter and ammeter, motor voltmeter and ammeter, and watt hour meter.

Performance Data: #71

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	17.2

2) Braking

Speed	Stopping distance (ft.)
46	153

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	106.0
Driver #2	104.5

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	67.5
30 cruise	50'	59.5
Idle	10'	49.5

Emissions Data: #71

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	0.59	27	20
CO	1.67	1000	1500
NO	6.09	1041	1000

Part. (gm/mile): No data

Fuel Economy: #71

147.6 miles/million Btu

75

CO-WINNER-CLASS V

University of Toronto

Entrant: #75

Class: Electric-I.C.E. Hybrid

Team Captain: Douglas Venn
Mechanical Building
University of Toronto
Toronto 5, Ontario
Canada

Body: Fabricated fiberglass

Chassis: Custom built-constructed from 1970 Chevelle front end and 1967 Corvair transaxle and rear suspension.

Vehicle Weight: 4160 lbs.

Power System:

Propane-fueled I.C.E. used as prime mover, transmitting power through an electric power system, or mechanically through a drive shaft, or in parallel with electric drive. Electric drive may also be used on battery power with I.C.E. shut down.

Electric Drive - Two Delco 12 KW motor-generators. One (used as motor) drives the main driveshaft by a belt drive, the other (used as a generator) is mounted forward and driven by the engine. Ten 90 amp-hour lead-acid batteries used for electric energy storage.

Electric power controlled by an SCR chopper with automatic control logic circuitry.

Engine:

302 C.I.D. Chevrolet V-8, modified to run on propane.

Transmission:

4-speed manual (Corvair transaxle)

Fuel System:

Propane tank in rear of vehicle. Two Algas gaseous carburetors feed into a split plenum chamber which is mounted on a Weber intake manifold. Balance line between plenum chambers provides uniform vacuum and better mixture distribution.

Exhaust System:

Dual system with regular manifolds. A platinum catalytic reactor and a conventional muffler followed each manifold, in the order given.

Emission Control:

1) Engine intake and exhaust ports were ported and polished. Larger, high temperature, valves were installed. Displacement of each upper combustion chambers rendered precisely the same. These modifications provide better and more uniform breathing characteristics.

2) Catalytic reactors installed to oxidize HC and CO.

Additional Modifications:

1) Compression ratio raised from 7.1:1 to 11:1 to achieve more complete combustion in the cylinders and lower exhaust temperature.

2) 1965 truck hydraulic lifter camshaft with short duration (252°) and later opening and closing times installed.

3) Scintilla vertex magneto ignition system installed.

4) Dual electric fans installed to assist regular belt-driven fan in cooling the 1970 Buick radiator.

5) Aluminum wheels and Dunlop six-ply radial 185 x 15 tires installed.

Performance Data: #75

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	6.3
0-45	12.4
20-50	10.6

2) Braking

Speed (mph)	Stopping distance (ft.)
27.0	35
49.5	131

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	80.8
Driver #2	78.5

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	82.0
30 cruise	50'	72.0
Idle	10'	66.5

Emissions Data: #75

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	2.59	58	46
CO	1.06	1000	1000
NO	2.35	336	615

Part. (gm/mile): 0.01

Fuel Economy: #75

143.8 miles/million Btu

UNIVERSITY OF CALIFORNIA AT SAN DIEGO

Entrant: #80

Class: Rankine Cycle (steam)

Team Captain: Ray Salemme
c/o Dr. Stanley Miller
Chemistry Department
University of California, San Diego
La Jolla, California 92037

Body and Chassis: American Motors Javelin

Vehicle Weight: 3600 lbs.

Power System: Steam engine (boiler, expander, and condenser) built by entrant team.

Water supply - Original gas tank used as water tank. Feed water pump, adapted from hydraulic oil pump, can supply water at 1000 P.S.I. to boiler.

Boiler - Recirculating type, consisting of 300 ft. of copper pre-heat tubing (5/16 in. o.d.) connected to 100 ft. of chromemolybdenum steel tubing (3/8 in. o.d.), which connects to a header pipe of mild steel (3 in. o.d., 1-3/4 in i.d.)

32 u-tubes (1/2 in o.d.) extend down from header into boiler. Water circulates through u-tubes, and steam exits from ports at top of header pipe.

Pressure switch in header turns flame on or off.

Expander - Modified Harley-Davidson 74 C.I.D. motorcycle engine. 2 cylinders made, push rods and valves removed, and front plate with timing pulleys and alternators added. Steam inlet valve is cam actuated piston type, preceded by a throttle valve for speed control.

Exhaust ports with check valves at the bottom of each cylinder allow exit of steam.

Condenser - Specially made auto-radiator type with electric fan for air flow. Water is returned to water tank.

Drive Train:

Engine drives a 1962 Cheverolet 3-speed manual transmission through a clutch. This allows the engine to idle and drive alternators when car is stopped. Drive shaft delivers power to 2.87:1 rear end and wheels.

Fuel: Propane

Fuel System:

35 gallon liquid propane tank in trunk for fuel storage. Fuel passes through pressure regulator, them to vaporizer-burner. Burner consists of combustion can inserted through the boiler u-tubes with forced air supplied by electric fan. Spark ignition operates whenever burner is on.

Performance Data: Not tested

Emissions Data: No data

Fuel Economy: No data

WORCESTER POLYTECHNIC INSTITUTE

Entrant: #83

Class: Rankine Cycle (steam)

Team Captain: Allen Downs
Higgins Labs
Worcester Polytechnic Institute
Worcester, Mass. 01609

Body and Chassis: 1970 General Motors Chevelle

Vehicle Weight: 4000 lbs. (approx.)

Power System:

Closed cycle steam engine built by entrant team consisting of a steam generator, expander, condenser, and feed water tank.

Steam Generator - Three-stage monotubular design. Incoming feedwater is heated to just below its boiling point in the first stage. Vaporization takes place in the second stage. The combustion chamber is located above the tubing package. Fuel (kerosene) is atomized, mixed with air supplied by blower, and ignited by modified spark plug. Combustion air is preheated in an outer jacker. Fuel is burned with excess air present for more complete combustion.

Expander - 99 C.I.D., 6 cylinder, modified Kiekhaefer-Mercury marine engine. Steam, distributed by chain driven rotary valve, is fed into spark plug openings and exhausted through intake ports. Original exhaust ports were plugged.

Condensing system - Feed heater extracts heat from exhaust steam to preheat feedwater. Exhaust steam then enters a spray-condenser, where a water spray removes remaining superheat. Saturated steam and water then enter a set of helicopter oil coolers connected in series. Condensed water then enters the feedwater tank.

Steam pressure and temperature are automatically regulated by a feedback control system which turns fuel and/or water on or off. Main feedwater pump is driven by expander. Auxiliary electric pump provided for low speeds.

Operator Control:

Hand throttle wheel opens or closes plug valve in steam line. A cutoff lever varies portion of expander stroke during which steam is admitted to cylinder. Cutoff of 0°-120° available, forward and reverse. Cutoff is controlled in rotary valve which distributes steam to cylinders. Brakes, steering, and ignition switch are operated as in a conventional car.

Drive Train:

Direct drive from expander to differential of 2.73:1 ratio, which drives rear wheels.

Miscellaneous Features:

1) Accessories are driven by a pair of roots - type motors which operate on exhaust steam from two expander cylinders.

2) Electrical system operates at 24 volts. Load varies from 65 to 145 amps.

3) Instruments include:

    Steam pressure
    Steam temperature
    Exhaust gas temperature
    Expander tachometer
    Exhaust steam pressure
    Condenser pressure
    Feedwater temperature
    Feedwater level
    Fuel level
    Ammeter
    System elapsed operating time
    Steam generator firing elapsed time.

Performance Data: #83

1) Acceleration

Speed range (mph)	Time (sec.)
0-20	36.5

2) Braking

Speed (mph)	Stopping distance (ft.)
20	44
21	33

3) Urban Driving Cycle

Not tested

4) Noise Levels

Test Mode	Microphone distance	dB (A)
30 WOT	50'	69.0
30 Cruise	50'	68.0
Idle	10'	62.0

Emissions Data: No data

Fuel Economy: No data

WINNER-CLASS III

Massachusetts Institute of Technology

Entrant: #90

Class: Brayton Cycle (turbine)

Team Captain: Michael L. Bennett
12 Lawrence Road
Brookline, Massachusetts 02146

Body and Chassis: 1970 Chevrolet C.10 half-ton pickup truck

Vehicle Weight: 5200 lbs.

Power System:

Turbine-Electric configuration. Gas turbine drives an alternator which provides A.C. power to a rectifier system. D. C. power from the rectifier is delivered to a D.C. motor, which drives the rear wheels through the 4.11:1 differential.

1) Turbine - Airesearch GTP-70-52 gas turbine. 225 horsepower maximum output, rated at 136 H.P. at sea-level atmospheric pressure and 80°F.

2) Alternator - General Electric model 2CM 357A1. Provides 150 KW, 400 c.p.s. A.C. at 6000 r.p.m.

3) Motor-Inland M-12004-A series wound D.C. Motor. Rated at 100 H.P. continuous, 600 H.P. maximum output.

4) Rectifier - Designed and built by entrant team.

Turbine, alternator, and rectifier are mounted in truck bed. Electric motor is mounted in engine compartment.

Control Features:

Constant motor torque or current control. Turbine and alternator run at constant speed, with output controlled by excitation applied to field windings.

Fuel:

JP-1 or JP-4 (aviation fuel)
Fuel control unit of the turbine is controlled by mechanical, thermal, pneumatic, and electronic feedback units. Fuel tank mounted in bed.

Miscellaneous Features:

1) Heavy-Duty wheels and tires mounted.

2) Aluminum camper shell installed over truck bed to cover turbine, etc.

3) Acoustic intake and exhaust mufflers installed.

Performance Data: #90

1) Acceleration

Speed range (mph)	Time (sec.)
0-30	12.0
0-45	27.1
20-45	21.0

2) Braking

Speed (mph)	Stopping distance (ft.)
28	44
47	133

3) Urban Driving Cycle

	Best time (sec.)
Driver #1	114.0
Driver #2	110.6

4) Noise Levels

Test Mode	Microphone Distance	dB (A)
30 WOT	50'	89.5
30 cruise	50'	89.5
Idle	10'	105.0

Emissions Data: #90

	Cold Start Detroit (gm/mile)	Hot Start Cambridge (ppm)	Hot Start Pasadena (ppm)
HC	5.73	no data	no data
CO	78.50	no data	no data
NO	6.24	no data	no data

Part. (gm/mile): No data

Fuel Economy: #90

24.0 miles/million Btu

APPENDIX C

A HISTORY OF ORGANIZATION COMMITTEE ACTIVITY

or

HOW NOT TO ORGANIZE A CLEAN AIR CAR RACE

The large number of factors which contributed to the success of the 1970 Clean Air Car Race (CACR) makes a complete journal of the event very difficult to write. A chronological summary of the development of CACR will provide some insight into the total organization of the competition. The history of CACR, however, is not a distinct sequence of events, but, rather, a hazy collection of many complementary and sometimes conflicting actions.

THE GREAT ELECTRIC CAR RACE OF 1968

The chain of events leading up to the CACR really began in the summer of 1968 when Wally Rippel, an undergraduate at the California Institute of Technology (CIT or Caltech for short), challenged the Massachusetts Institute of Technology (MIT) to a cross country electric car race. Though the M.I.T. administration was doubtful about the value of such an event, some enterprising students accepted Rippel's challenge. Leon Loeb, David Saar, and William Carson, all mechanical engineering (M.E.) undergraduates, took on the task of building an electric car with faculty support from Professor Richard D. Thornton of the M.I.T. Electrical Engineering (E.E.) Department.

After several delays, the race began on August 26th with the two teams traveling in opposite directions over the same route between Cambridge and Pasadena. Temporary electric charging stations had been set up at more than 50 locations along the race route to provide the electrical energy needed by the experimental vehicles' battery packs. The M.I.T. car arrived at Caltech a little over a week later and the Caltech entry at M.I.T. about 36 hours after that. Both vehicles had experienced numerous mechanical and electrical failures en route, but the penalty assessment for towing, which the Caltech team had managed to avoid, ultimately cost the M.I.T. boys an apparent victory.

Eventually, this happening became known as the Great Electric Car Race of 1968, but was considered by the media to have been more a college stunt than a serious attempt to solve the automotive air pollution problem. Although widespread public attention had not yet been drawn to the emissions control problem of the internal combustion engine (ICE), the great amount of publicity generated by this "stunt" was partially responsible for sowing the seeds of the Clean Air Car Race. Another major incentive for pursuing a course of university involvement in the fields of automotive propulsion and pollution emission control was the educational experience which the student participants in the 1968 competition had taken back with them to their respective schools.

EARLY DAYS OF THE CACR

The conceptual evolution of the Clean Air Car Race took place in the fall of 1969. Correspondence between Professor Thornton at M.I.T. and Professor Jerome Shapiro at Caltech speculated upon the possibility for a more novel and practical type of automotive competition, not restricted to electric cars but open to all forms of low-pollution vehicles. Dr. Milton Clauser, then director of M.I.T.'s Lincoln Laboratory, had followed the Great Electric Car Race closely and had talked frequently with Professor Thornton about the prospects for a sequel to the 1968 competition. In turn, Milton Clauser and his twin brother, Dr. Francis Clauser, Dean of the Engineering School at Caltech, became prime movers in laying groundwork for the new race by initiating contact with the General Motors Corporation to determine whether significant industrial support could be mustered.

By late fall (the end of November, 1969), a public announcement concerning the rules for participation in the CACR and a proposed structure for the recently formulated competition had been issued. The event would be divided into three parts: vehicle performance testing in Cambridge, a cross-country rally from Cambridge to Pasadena, and exhaust emissions testing in Pasadena - all to take place in the late summer of 1970. Test vehicle entries could be designed and built by any group of individuals, including commercial companies, but could be driven only by college students. Early speculation projected that as many as 15 to 20 teams might eventually participate in the CACR.

No one had expected the unusually overwhelming enthusiasm which greeted the proposed intercollegiate competition in engineering. By mid-January, over 15 teams had already indicated intentions of participating and the faculty group could no longer effectively handle the administrative load required to organize the CACR. It was decided to make the organization of the race the responsibility of a student committee, composed of equal numbers of students at M.I.T. and Caltech, with overlapping responsibilities. Robert G. McGregor, a master's degree candidate in M.E., was soon chosen as the M.I.T. student chairman through the screening efforts of the persistent Milton Clauser. Caltech would not appoint its student chairman for a month and a half to come.

THE EMERGENCE OF A STUDENT ORGANIZATION COMMITTEE

It soon became clear that the M.I.T. committee would play a dominant role in organizing the CACR, largely because of a much larger source of manpower and a greater initial commitment to the concept. By early February, Bob McGregor had established a preliminary committee structure which then consisted of an assistant to the chairman (Steve McGregor, a junior majoring in history at Boston University), a director of finances (Dick Holthaus from the M.I.T. Sloan School of Management), a director of public relations (Ty Rabe, a sophomore in mechanical engineering and business management at M.I.T.), and a director of communications (Jason Zielonka, a senior in electrical engineering at M.I.T.). Though titles and committee personnel would change between then and the running of the race, each position with its associated responsibilities was clearly defined from the outset to reduce confusion when the juggling actually began.

Steve McGregor's initial role was to keep the chairman informed of ongoing activities during the early planning stages of the race. In May of 1970, he would become race director and, together with a to-be-appointed race coordinator, would make all final arrangements connected with cross-country travel of the CACR participants. These included overnight accomodations for the entrant teams, impound areas for the vehicles, storage areas for the wide variety of fuels used by the cars, and coordination with state and municipal officials to insure that all laws and motor vehicle regulations were understood and adhered to.

The responsibilities of the finance director included raising the necessary funding for the race, allocating the resources appropriately, and serving as a liason between contributors and the race organization committee. The original budget for Organization Committee activity and staging the 17 day competition was estimated at $100,000 but the final budget would be several times that much.

The mission of the public relations director was, as might be supposed, to arouse public interest in the problem of automotive air pollution and the potential afforded by the CACR in providing some of the available solutions. A major consideration from the outset in conducting an effective public relations effort was the establishment of a Race Information Center which would compile and disseminate daily information to the media during the cross-country rally.

The communications director, in addition to being the office manager, was in charge of handling correspondence between race participants and the organization committee. At organization committee meetings, Jason reported on all entrant team questions regarding qualification, testing procedures, and general interpretation of race rules.

THE FIRST MIT - CALTECH ENCOUNTER

On March 17, 1970, a meeting held at MIT in Cambridge brought together for the first time the joint MIT-Caltech Committee to draw up a detailed set of preliminary rules for the regulation of the CACR. Prior to the meeting, Dr. Francis Clauser at CIT had succeeded in locating an interested student willing to assume responsibility for Caltech's role in organizing the event. And so Blair Folsom, a Ph.D. candidate in mechanical engineering, became the first Caltech student to involve himself in the already hectic task of preparing for the fast approaching summer competition.

As a result of the March 17 meeting, final qualification requirements for official entry into the race were established. A schedule of events for the competition was presented which included performance and exhaust emissions testing of all the entrant vehicles during a week of pre-race activity at M.I.T. The week of August 17-23 was set aside for this purpose and would also include the presentation of technical papers on the respective vehicle power plants by each competing team. Caltech agreed to host a four-day symposium on its campus following the race to assess CACR results and to review the state-of-the-art concerning the control of ICE emissions and the future prospects of alternate automotive propulsion systems. During this period, the test vehicles would undergo final exhaust emissions testing to determine whether the various emission control systems had deteriorated over the course of the race. Concurrently, a panel of experts in the automotive field would subjectively select an overall winner of the competition. The final event at Caltech would be an awards banquet to be held the night of Wednesday, September 2nd.

The March meeting also established five categories of entrant vehicle power plants for competition purposes: internal combustion engines, steam engines, pure battery-powered vehicles (electrics), electric-hybrid systems (see Chapter III for definition), and power plants using either liquefied natural gas (LNG) or liquefied petroleum gas (LPG - commonly possessing propane as the dominant constituent) for fuel. An entry slot was later made available to turbine powered vehicles employing a Brayton cycle of operation. In the competition, a class winner would be selected for each vehicle power plant category on the basis of a scoring formula devised at a later date by the organization committee.

Wally Rippel, the instigator of the 1968 race, also attended the March meeting. He had continued his work on electric vehicles at Cornell University and believed that electrics would be at a disadvantage in a race which included other types of power plants. He had organized an all-electric competition which drew 10 to 15 entrants during the course of the spring and was asked to consider merging his race with the CACR. Although he refused in March, later difficulties in raising funds would force him to disband the Cornell group. In mid-summer, some of those electric teams were absorbed into the CACR.

SPRING TIME ACTIVITY AT MIT

The tempo of organization committee activity accelerated dramatically following the March meeting. Mike Martin (an M.I.T. junior in E.E.) began the task of devising a suitable emissions scoring formula and planning for the exhaust emissions testing to be done in conjunction with the race. Craig Lentz (an M.I.T. graduate student in the Sloan School of Management), who had originally joined the Committee as an assistant to the Finance Director, was now appointed by Bob McGregor to the key post of coordinator, where he became the chairman's equal in practically all matters. Two more M.I.T. students, Alberto Darna (a junior in business management) and Ron Francis (a junior in civil engineering), were appointed to select the race route and set up the electric charging stations respectively. In addition Dieter Herrmann (also a junior in management) began to design the vehicle performance test procedure.

Jason Zielonka, the communications director, had been literally inundated with mail and questions. There was no doubt that CACR had struct a responsive chord among university groups and private industry across the nation. To speed up communications, a preliminary registration form was drawn up and mailed to all who had expressed an interest in participating as an entrant team in the competition. A steady flow of press releases, not only from M.I.T., but also from universities which planned to enter the race, kept a generally receptive public thoroughly informed of progress.

During this time, Ty Rabe, with the help of the assistant director of M.I.T.'s Office of Public Relations, Robert M. Byers, was focussing his attention on the establishment of a Race Information Center (RIC). With more than 30 entrant teams already registered, there could be up to 1,000 miles separating the first and last cars during cross-country travel, thereby making it extremely difficult to provide the media with a comprehensive view of what was happening on a daily basis. A Race Information Center could certainly be used to collect data phoned in daily by each of the entrant teams to be relayed in a solid chunk form to the media, principally the wire services. Because national news must compete with international news at the coastal headquarters of the wire services, the Chicago outlet became the favored location for the RIC. Attempts to draw funding from the media failed to succeed, and consequently, RIC remained only a concept until about a month before the August 24 starting data.

Another critical activity of the spring months was raising financial aid and securing industrial services for the CACR itself. A proposal for funding the organization committee had been made by Milton Clauser to the General Motors Corp., but had remained deadlocked for several months. The M.I.T. administration recognized CACR as a student activity but feared a budget policy conflict if GM were to make a direct grant to the M.I.T. supported student committee. In April, a compromise was reached whereby GM agreed to give twenty 1970 Chevelles with a $2,000 cash grant per vehicle to the committee for distribution to race participants.

By submitting an application form drawn up by the organization committee, student groups with sound engineering ideas but limited finances could request one of the GM vehicle grants. The committee screened 33 such applications and had awarded 15 grants by the end of May, at which time the remainder were returned to GM. Aside from the immediate assistance provided by this grant, the committee continued to benefit from the interest and support of many people at the General Motors Technical Center and Office of Education.

Though the GM grant was significant in promoting increased participation in the race, it did not contribute to financing committee activities, which were still in need of major support. For the time being, the committee had to exist leading a rather hand-to-mouth life, relying on personal contributions of $500 to $5,000 which were secured through the personal efforts of the M.I.T. Corporation Chairman, Dr. James R. Killian. In April however, CACR drew the interest of the National Air Pollution Control Administration (NAPCA) which eventually proved to be its largest source of monetary support. (NAPCA at the time was an agency of the Department of Health, Education and Welfare (DHEW) and has since become the Air Pollution Control Office (APCO) of the Environmental Protection Agency (EPA).)

NAPCA's original commitment consisted of an agreement to fund the travel expenses of committee members and a guarantee of individual $5,000 cash prizes to be presented to class winners and the overall winner of the competition at the awards banquet in Pasadena. But the agency's interest in the outcome of the race went beyond money. Various people in NAPCA displayed a continuing willingness to help the committee develop appropriate emissions testing procedures and devise a scoring formula for rating the exhaust emissions data fairly.

Throughout the spring, the committee had also been in contact with the Ford Motor Company requesting financial assistance. While direct monetary support did not meet with their approval, Ford did indicate a willingness to discuss other types of assistance, including vehicles and the use of their Mobile Emissions Laboratory. This last possibility provided the committee with the first real breakthrough in the problem of how to conduct emissions testing in the Cambridge area during pre-race activity.

The 1968 electric car race had illustrated that a better network of charging stations would be necessary if electric vehicles were to be at all successful in the 1970 CACR. Calculations revealed that as many as 75 of these units, separated by distances varying from 40 to 80 miles, would be needed along the route. The help of the Electric Fuel Propulsion Company of Detroit and the Edison Electric Institute of New York was sought in laying plans for this elaborate network. Through the efforts of Dave Saar and Ron Francis, both M.I.T. undergraduates, a charging station was designed consisting of a circuit breaker, a watt-hour meter, and a six-foot connector cable, all enclosed within a metal container. The committee believed that the industries involved would construct, sell, and install these units now that the design work had been completed, but it later turned out that the committee had to assume responsibility for the selling task - certainly not an easy undertaking with over 35 electric utility companies to be contacted.

Beginning in May, the pace of the CACR organization committee's activities quickened despite the student strike and the postponement or cancellation of classes and examinations at many Boston area colleges and universities. From mid-May until the awards banquet in September, the committee would continue to function as an almost round-the-clock operation.

NAPCA's interest in the race also continued to increase during May, for it felt that the CACR could contribute to its Clean Car Incentive Program, designed to encourage the development of low-pollution vehicle power plants capable of meeting the 1975 Federal exhaust emissions standards. NAPCA indicated its willingness to support both a professional publicity campaign for CACR and a thorough documentation effort of race activities. The organization committee decided that professional publicity was inconsistent with a competition that was to be student-oriented and declined funding for such a campaign. The offer to document the race, however, was greeted enthusiastically. Documentation would include both written and filmed accounts of the race and its participants. There would be three major films produced: two for general audiences in 50 and 30-minute versions, a 30-minute technical film, and a 10-minute theatrical release for use as a selected short in neighborhood theaters. Contracts for the general audience films were awarded in July to Fournier and Pytka of New York and for the technical film to the Tech Films Corp. of Watertown, Massachusetts. The organization committee accepted the task of providing written documentation, the result being this entire report which you are now reading.

By exam time in late May, the committee was still actively seeking support in the nature of both funding and in-kind contributions, such as the unconventional fuels being used by some of the entrants teams and equipment capable of measuring vehicle exhaust emission levels accurately. Negotiations had been opened with many industrial concerns, many of which would eventually prove useful in preparing for the race.

SUMMERTIME ACTIVITY

The summer months absorbed the committee in carrying out original plans and making new arrangements to cope with an ever-changing set of situations. The committee was expanded as new tasks arose with every attempt being made to do the best possible job despite a severely short timetable and practically no prior experience in an undertaking of this magnitude.

In June, the committee's full-time staff began receiving salaries of $500 per month and working 12 to 16 hours a day just trying to keep up with the mountains of paper work. More than fifty preliminary entrant teams had registered, and the end was not yet in sight. A bi-weekly newsletter was now being published in an attempt to keep competitors, donors, and other interested people informed of the current status of the race.

As its first summer task, the committee moved into a larger office to accommodate the ever-growing file system and staff of personnel. The new organization committee domain was a vacated classroom. Since hardly any equipment was available from M.I.T., the necessary desks, tables, and chairs were removed from nearby classrooms during midnight raids.

The burden of trying to coordinate a dual-committee separated by 3,600 miles was eased somewhat in the summer by M.I.T.'s assumption of responsibility for almost all pre-race activity. The activities of the Caltech organization committee were still at a low level at the beginning of June. Because Caltech is a much smaller and more specialized institute than M.I.T., it was difficult for Blair Folsom to arouse enthusiastic support in either the administration or the student body. In mid-July, Blair was forced to step down as chairman of the Caltech group in order to meet his own project commitments as a student research assistant. He was replaced by Hal Gordon, who then organized a small committee to make arrangements for the post-race activities in Pasadena.

By mid-June, Dick Holthaus had stepped down from his post as finance director to accept an outside summer job. Bob McGregor appointed Ron Francis to fill the vacated position in addition to continuing with his former task of coordinating the arrangements for the construction, purchase, and installation of the charging stations. Soon thereafter, Mary McNulty (a junior majoring in Health Dynamics at Boston University) joined the committee to serve as general office manager, thereby giving the communications director, Jason Zielonka, more time for the daily phone calls requesting information, the mounting piles of unanswered correspondence.

Mustering $$$ and Services

During the first weeks of the summer, agreement with NAPCA concerning the details of the documentation contract consumed long hours of negotiation between the legal staffs of M.I.T. and NAPCA. The $220,000 contract was finally signed in a down to the wire effort on the last day of the fiscal year, June 30th.

Early committee contact with local New England industrial firms began to pay off during the summer as public interest grew. The Boston Edison Company donated $3,000 to be used for organization committee student salaries and the Automotive Division of the Fram Corporation of Providence, Rhode Island, supplied $1,100 to purchase trophies for race winners. The Lowell Gas Company of Lowell, Massachusetts, agreed to send along an 11,000 gallon tanker during the race to supply liquefied natural gas (LNG). Engelhard Minerals and Chemical Corporation of Newark, New Jersey, whose catalytic reactors were used on many CACR entrant vehicles, purchased the unleaded gasoline required by a number of the ICE test vehicles and shipped the fuel to predesignated locations along the cross-country route. In addition, several smaller donations of equipment, manpower, and other services were offered to the committee as the summer progressed.

While these gifts did much to improve the overall situation, a lack of cash on hand still plagued the committee. In July, Bob McGregor traveled to New York City at the request of M.I.T. Corporation chairman, Dr. James Killian, with a prepared outline of plans and needs which he would use in soliciting funds. He returned with an officer authorization grant of $25,000 from the Rockefeller Foundation, thereby alleviating the financial crisis for the time being.

COMMITTEE PROBLEMS

Communications activity crescendoed as the number of preliminary entrants soared to a peak of 93 in late June. With Mary McNulty managing the office, Jason Zielonka spent many work hours a day both answering questions from the entrant teams, and on the telephone in response to queries for general information on the CACR. Although the bi-weekly newsletters were lengthened in an attempt to clarify details on rules and procedures, vast quantities of mail still poured into the office, with each letter being handled individually.

By far, the most time consuming problem -- and one which continued right through the running of the race -- was to arbitrate disputes and give sound definitions of the often-ambiguous rules. The committee as a whole sat in review on these matters, but consistently suffered from the lack of a clearly formulated policy for rule interpretation. Consequently, nearly all differences of opinion had to be settled on an individual basis.

In addition, as the activities of the committee members increasingly diverged into separate areas of responsibility, intra-committee communications broke down. At the end of July, daily committee meetings beginning at 6 p.m. were instituted to review all activities of the day as well as to discuss upcoming plans. These meetings were often long and tiring, but they did much to remedy th problem and were continued until the entrant teams arrived in mid-August.

The CACR Public Relations Program

Public interest in the event rose steadily during the summer due to a concerted effort by the M.I.T. Office of Public Relations to publicize the event. In June Mike Martin and Ty Rabe departed on an eighteen day, cross-country, publicity trip, beginning in Los Angeles and passing through 19 major cities along the proposed CACR race route, en route to Cambridge. Altogether, they visited more than 50 local and regional news media stations as well as some 15 entrant teams during their travels. News releases explaining different aspects of the competition were periodically mailed to over 700 interested journalists. Lapel buttons, bumper stickers, and posters depicting the CACR logo were ordered and distributed.

During late July and early August, a plan of operation for the

Race Information Center (RIC) was formulated. Entrant vehicles would call the RIC at least twice daily during cross-country travel on Wide Area Telephone Service lines and report their progress. These reports would be compiled and sent to the Associated Press and United Press International bureaus in Chicago. The RIC would also display an exhibit containing a large map of the U .S. to mark the race's progress and color photographs of each entrant team and vehicle. A location for the RIC was finally established when the Chicago Museum of Science and Industry acknowledged the committee's request for assistance by supplying both space and equipment. The Xerox Corporation donated a telecopier system for relaying information from the RIC to the wire services.

The final major task of the public relations group prior to the entrants' arrival at M.I.T. was to assemble press kits containing complete information for distribution to the media. The kits, which included a set of news releases, final race rules, buttons, stickers and posters, were mailed in early August.

The Exhaust Emissions Test Procedures

While Mike Martin was accompanying Ty Rabe on the public relations trip, Bob McGregor met with representatives from NAPCA, GM, and Ford to establish the emissions testing procedures for the CACR vehicles. At that time, more than 50 entrant vehicles were expected to compete in the CACR, all of which had to be tested prior to arrival in Boston in order to qualify for the competition and then three more times during the race for scoring purposes. McGregor accepted NAPCA's offer to coordinate the qualification testing program at 12 industrial laboratories across the country. Because not all of these laboratories had the necessary equipment to test vehicles according th the prescribed 1972 Federal test cycle procedure and because this joint group had doubts about the entrants' ability to meet the then-proposed 1975 Federal standards, it was agreed to use a hot start, closed, seven-mode cycle (see Chapter IV, Section A) and to evaluate these results as acceptable grounds for qualification in lieu of the former entrance requirements. When these tests were run in July and August, only a few teams were summarily disqualified.

The problem of pollution emission testing for race scores was a bit more difficult to resolve. The best solution would have been to conduct either two or three cold start tests using constant volume sampling equipment as prescribed in the 1972 Federal procedure. However, this would have meant a 12-hour "cold soak" for each car before each test; in addition, the only location in the U.S. where the necessary equipment could be found in sufficient quantity was Detroit. These constraints forced a compromise solution whereby the CACR vehicles would be given hot start tests in Cambridge and Pasadena using the continuous sampling technique. The Ford Motor Co. agreed to donate the use of its mobile emissions laboratory for the tests in Cambridge, while both the Olson Laboratories and the California Air Resources Board would supply the necessary mobile test equipment in Pasadena. The only cold start CVS test for each team would be done in the Detroit area, where the entrants would make a 24-hour layover; because of the limited time available for such testing during cross-country travel, a 4-hour cold soak would be used rather than the specified 12-hour test. NAPCA, Ford, GM, Ethyl Corporation, and Chrysler all donated their laboratories and personnel to run these tests.

The addition of the two hot start tests considerably complicated the emissions scoring formula (See Chapter IV, Section C); a new formula had to be devised to incorporate the hot start test results. After a long and occasionally heated three-way debate between the committee, the entrants, and NAPCA advisors, it was decided that Pasadena and Cambridge results would be compared against one another to show deterioration of the vehicle emission control systems during the race, while the Detroit measurements would constitute the most pertinent data in assessing vehicle potential.

Preparations for Cross-Country Travel

Meanwhile, Steve McGregor and Craig Lentz worked on the details of accommodating 300 to 400 people (the CACR caravan) at six different stopover locations for the period of cross-country travel. Early in the summer, introductory letters were mailed to potential hosts and local governments of these cities. Eventually, Steve and Craig established contacts within a college or university at all the cities except Odessa, Texas, where hotels turned out to be the only feasible housing facilities. In July, they embarked on a two week drive along the CACR route to complete arrangements and check driving times and mileage distances between the stopover locations. The Universities of Toronto, Michigan, Illinois and Arizona, as well as Central State College in Oklahoma, agreed to provide low-cost dormitory rooms for race personnel. In Odessa, the Inn of the Golden West, the Holiday Inn, and the Ramada Inn provided specially reduced prices on rooms. In all cities, either the educational institution or the Chamber of Commerce would also provide secured impound areas for the 150 race and trail vehicles. In addition, many of the cities decided to host banquets or barbeques for the entire race group. These arrangements weregiven a final check in early August when McGregor and Lentz each flew to three of the cities.

Ron Francis and a new member to the committee, Bill Charles (an MIT electrical engineering senior), also made a cross-country trip in July. Their job was to sell the electric charging stations to local and regional utilities along the race route. During their three weeks on the road, they sold more than 60 such stations, leaving only a few gaps in what was to become the first permanent transcontinental electric vehicle highway.

Committee Membership on the Rise Again

In late July, two new members joined the M.I.T. work force. Professor John B. Heywood from the M.I.T. mechanical engineering department became the committee's faculty advisor upon Dr. Milton Clauser's departure to assume his new position as academic dean of the Naval Post-Graduate School in Monterey, California. Al Harger, an administrative assistant in M.I.T.'s Division of Sponsored Research, was assigned to aid the committee full time on any and all CACR-related projects. Professor Heywood had done prior research work on automotive air pollution and consequently afforded immeasurable help to Mike Martin in understanding the technical aspects of the problem. Al Harger at the same time proved himself invaluable in arranging facilities for the committee and entrants in preparation for the week of pre-race activity at M.I.T.

With the addition of Heywood and Harger, the work load momentarily decreased. However, new jobs were constantly arising and often the committee had to rely upon friends and even family to help out. Beth McGregor and Mary Jane Lentz, the wives of the Chairman and Coordinator, pitched in by typing a large part of the committee's correspondence while Diane Lentz, Craig's sister, worked in a full time position as committee secretary. Rob Rabe, Ty's twin brother, joined the committee as a full time liaison with the two film companies, and Chris Exton, a Tufts University senior and long time friend of the McGregor brothers, handled all irregular jobs which did not clearly fall into any one area of responsibility.

M.I.T. to the Committee's Aid

In order to begin the arrangements for pre-race activity at M.I.T., Bob McGregor called for a meeting of administrative representatives from the various branches of M.I.T. in mid-July. The principal needs, as defined at the meeting, were, rooms, dining facilities, parking space and garage facilities, a location for the emissions testing lab, an information center, a press room, and rooms for seminars. With Al Harger handling most of the details, housing for the entrants was made available at both M.I.T. and Northeastern University in Boston. One of M.I.T.'s multi-level parking garages was reserved for CACR entrant team parking, and all other needed space and facilities were located on campus.

Preparation for CACR Vehicle Performance Testing

The performance testing of the CACR vehicles during the pre-race week had to be located off-campus, due to the great space requirement demanded by this event. After a great deal of discussion in early spring, the organization committee had decided to keep the performance tests as simple in nature as possible since the CACR entrants were, in fact, competing against the typical car on today's highways rather than designing a car for the Indianapolis Speedway. Basic tests for braking, acceleration, and road handling were established with maximum scores being awarded for performance characteristics that were comparable to a slightly better than average conventional automobile. Noise testing was to be done by the firm of Bolt, Beranek, and Newman, Inc. under contract from the Department of Transportation.

Bill Charles was placed in charge of the performance testing which would undoubtedly constitute a full time schedule of activity during the pre-race week. After a long search, he located the necessary space for conducting the performance testing at the Hanscom Field Air Force Base in Bedford, Massachusetts. He also secured test equipment which included a "fifth wheel", an accelerometer, and a strip chart recorder from the Cornell Aeronautical Laboratories in Buffalo, New York.

Last Minute Arrangements

The final major tasks confronting the committee prior to the arrival of the entrants at M.I.T. were the compilation of all CACR rules into a single publication, the formulation of a plan for race command and control during cross-country travel, and the selection of observers who would ride with the entrant teams to record data, traffic violations, and other pertinent information. A weekend effort in late July, headed by Craig Lentz and Jason Zielonka, managed to consolidate all rules and regulations published to date into a single document; but despite a deliberate attempt to cover all loopholes, last minute additions and changes still had to be made after the final copy had gone to print. Command and control required a well thought out plan for positioning the organization committee vehicles in the CACR caravan. A remote computer console would be installed in an econoline van, loaned to the committee by the Ford Motor Co. to be the lead vehicle or "Mobile Headquarters Van" (MHV) as it came to be known; the computer facilities would facilitate the computation of entrant team scores while on the road. Coordination of all activities would be done by telephone from the Race Information Center located in Chicago. Finally, volunteer student observers were selected by the committee from the Cambridge and Pasadena areas for the aforementioned purposes, as well as to provide the needed manpower for various activities during the pre-race week.

As the race entrants converged upon Cambridge from across the country, the committee re-evaluated its position. Charging stations still had to be set up in more than 60 locations along the route due to delays in construction. All arrangements at the stopover cities were tentatively complete. The budget had been more or less balanced and the only remaining major expense, observer travel costs, had been picked up by NAPCA. Fund raising efforts had been discontinued and attention was redirected to the vast amount of accounting involved in securing travel advances for the 60 committee members and observers. The pre-race schedule had been drawn up. Only a few other minor details remained to be taken care of, or so it seemed.

PRE-RACE ACTIVITY AT MIT

On the weekend of August 15, the CACR entrant teams arrived at M.I.T. to begin the most grueling 20 days of the summer. Despite previous attempts to complete all necessary arrangements, committee members found a seemingly never ending list of new and last-minute jobs. The daily schedule had its share of crises, with work often continuing into the early morning hours. Unexpected and sometimes uncontrollable problems had to be solved at a moment's notice as mistakes in planning became evident. Despite the mounting pressure, race activities went on.

The schedule for the pre-race week was an extremely busy one, sandwiched between a welcoming banquet which began the week's activities, and a kick-off banquet which completed them, and a barbeque inbetween. In addition to the performance and emissions testing scheduled to last the entire week, there were evening meetings for the team captains to vote on rule modifications, nightly meetings for observers to discuss their responsibilities, and midnight hour committee meetings to review the planned activities for the following day. Two days were devoted to a round of seminars in which the entrant teams presented technical papers on their vehicle power plants. There were two public showings of the CACR test vehicles during the week, one for M.I.T. and Caltech alumni at M.I.T. and one for the general public at the Museum of Science in Boston. On Saturday, August 22, a parade with bands, drum and bugle corps, and the CACR test vehicles made its way from the Prudential Center in Boston to M.I.T.'s Briggs Field in Cambridge. Throughout these activities committee members were constantly trying to find time for last minute details.

The hectic locus of activities during this week was the CACR Information Center located in M.I.T.'s Student Union. There the entrants received special picture identification badges for security purposes, completed registration, paid for their pre-race housing, received a detailed schedule of events, and picked up all messages and mail. The center was manned by a full time staff of committee members and observers, but extra help was often needed to answer phones or relay information. Three large bulletin boards were constantly filled with news: changing the messages on these boards created an almost full time job for one observer. In short, the Information Center provided the only regular means of communication between the committee and the entrants.

Throughout the week public relations was handled in a specially arranged press room, staffed by Ty Rabe, Bob Byers and a secretary from the M.I.T. Public Relations Office. Visiting press representatives received identification badges and several phones were made available for their use as well as comprehensive information packages on the CACR.

Emissions testing started on Monday, August 17, and continued smoothly to its scheduled completion on Friday, August 21. The actual testing was handled entirely by Ford's staff of engineers assigned to the Mobile Emissions Laboratory. The only difficulty encountered was that many experimental cars, especially the unconventionals, were not prepared in time for the testing due either to late arrival at M.I.T. or unforeseen breakdowns while on campus. Mike Martin spent the entire week scheduling the emissions tests and helping a staff of NAPCA engineers analyze the results.

Bill Charles did not have as much luck in coordinating the vehicle performance testing. Heavy rains on two separate occasions during the week created impossible conditions on those particular days for all phases of the performance testing except the noise measurement. Because of Monday's rainstorm, it wasn't until Tuesday when he discovered that all the tests, especially the noise measurement, were taking longer than had been anticipated. In addition, the fifth wheel used for monitoring vehicle acceleration and speed broke when it slipped from one of the vehicles during a trial run. It took half a day before testing could be resumed to secure a portable radar rig to replace the fifth wheel measurement system. Only by eliminating some of the noise tests and working thereafter from dawn until dusk were he and his staff of observers able to complete the testing on time.

In the evenings, the race captains met with Bob McGregor and Craig Lentz to vote on rule changes, discuss general complaints, and file protests. The major item of debate throughout the week was whether or not to include a fuel economy run as part of the CACR competition. After several proposals had been advanced and reviewed, the recommendation to measure vehicle fuel consumption between Ann Arbor, Michigan and Oklahoma City, Oklahoma, was voted on and passed at the Tuesday evening meeting.

At the observer meetings, Craig Lentz reviewed the CACR rules and outlined the methods of command and control. Observers were to record driving times, fuel consumption, and infractions of the traffic laws as well as calling the RIC at least twice daily to report the location and condition of their test vehicle. Craig Lentz and Ty Rabe compiled written instructions and observer report forms containing all pertinent information to be recorded and phoned in. At the same time, Steve McGregor was completing the route guide document which contained detailed maps of the race route and the locations of refueling stations for use by the entrants. Ron Francis had already prepared similar guides pertaining to the charging stations for the electric vehicle entrants. These documents were finally completed distributed to the entrants at the command and control meeting held the day before departure from M.I.T.

The only major crisis of the pre-race week was the press's charge of commercialism leveled at the CACR competition. As early as June, Bob Byers had warned the committee about this possibility, but because the original concept for a Clean Air Car Race had included both university and industrial involvement, the problem was almost unavoidable. Entrants were warned that their industrial backers could not use the test vehicle as a public relations gimmick, but there was no way to stop companies and advertising agencies from bombarding the media with press kits, releases, and PR men.

When commentary occurred during the pre-race week, every attempt was made to point out the worthwhile aspects of the event. The fact that the race would have been impossible without industrial support and that only a few of the multitude of industries supporting it had sought publicity for themselves was clearly stated.

On the night before the start of the race, the committee held its longest meeting. Committee vehicles and entrant test vehicles were assigned starting time, observers were assigned to the various entrants teams, and a few last-minute details concerning command and control were discussed. When the meeting broke up, the starting time of the race was only three hours away.

THE CROSS-COUNTRY RALLY

Thus, at 3 a.m. on August 24 the Clean Air Car Race became the mobile exposition that it was intended to be. Forty-three vehicles had qualified for the cross-country competition, having passed the rigorous testing of the previous week. Starting line activity, despite the earliness of the hour, revealed a high degree of entrant team enthusiasm and eagerness to set out on the trans-continental journey.

To facilitate control of the race, the organization committee made use of five special vehicles donated by Ford and General Motors. Pacing the entrant teams was the committee's Mobile Headquarters Van (MHV) which customarily departed two to three hours earlier then the main race body. Its primary mission was to arrive at the daily destination with sufficient lead time to ensure that arrangements had been made for the arrival of the CACR cavalcade. Two other committee vehicles were dispersed among the race pack for the purpose of establishing the normalized driving time for each leg. Another committee car, keeping pace with the electric vehicles, was used to finalize the installment of electric charging stations; consequently, it lagged about twelve hours in general behind the CACR pack. The fifth committee vehicle trailed the race by 24 to 36 hours. The purpose of this backup car was to switch observers stationed with struggling entrants and to act as a liason with those teams forced to lag behind.

Race control while on the road was augmented by the Chicago-based Race Information Center (discussed earlier in this appendix) which maintained a master chart listing of all CACR vehicle locations. A computer console located in the MHV further aided the committee in updating race results by tabulating entrant team rally scores for each leg. The aforementioned observers were an extension of the committee in that they recorded entrant team driving times and noted rule infractions. Observers were assigned one to a car and were rotated daily. No entrant team received the same observer more than once during cross-country travel and no observer was assigned to a team which originated from the observer's academic institution.

At the end of each leg, the committee set up an information and reporting center adjacent to the MHV. This area also constituted the impound location for the CACR test vehicles and were of primary importance for two reasons: they provided display areas where the cars could be inspected by interested members of the public and they afforded the necessary security for the overnight stopovers. Teams checked in with the committee upon arrival at the impound area each evening while observers turned in their reports for tabulation of the leg scores.

Race control, essential as it was, comprised only one major facet of the cross-country jaunt, as there is much to be said about the actual passage of the CACR caravan. The first vehicles to leave M.I.T. in the early morning hours of August 24th were the electrics. The reason for this early embarkment stemmed from the fact that 30 miles per hour (mph), including time for recharging the battery packs, was an optimal average speed for these entries. Thus, early starting times had been assigned to electric vehicles for the entirety of the race schedule in the hope that they could keep up with the main race body. As the race progressed, this effort proved fruitless as the electrics trailed further behind with each ensuing leg.

Indicative of the plight of the electrics were the Stevens Institute of Technology and the Cornell entries, the only electric cars to successfully complete cross-country travel in the allotted time. Both endured multiple charging problems due to reverse phase rotation at many of the charging stations and spent over 24 hours travelling time on five of the seven legs. It was not surprising when the Cornell team stopped in St. Louis for 12 hours of enforced recuperation due to physical fatigue. Mechanical malfunctions continually hampered the progress of the two cars: Cornell suffered an engine burnout in San Deigo; S.I.T. underwent a similar burnout in Buffalo and suffered from bent tie rods in California; in addition, both teams sustained several flat tires during the race passage. Consequently, both cars arrived in Pasadena more than forty-eight hours behind the main race body.

Except for the electric entries, the CACR test vehicles departed from M.I.T. between 5:30 and 7:00 a.m. on the morning of the 24th. This first leg of the race was 541 miles and terminated in Toronto where the Canadians received the CACR with open arms. An exhibition lasted from 8 to 10 p.m. at the city hall complex and all CACR affiliated personnel became guests at a cocktail mixer held at the display area. In addition, meals were provided at no cost by the Ontario Department of Tourism. Overnight accomodations were located on the University of Toronto campus while the race vehicles were impounded until the next morning at the U. of Toronto stadium.

The distance for the second leg was comparatively short: 243 miles. The leg consisted of passage through Canada to the Detroit-Ann Arbor area. As has been already stated, this was the sight of the cold start emissions testing for all CACR vehicles. Arrangements had been made to conduct testing at five seperate locations where adequate lab facilities had been established; the test facilities were provided by General Motors, Ford, Chrysler, Ethyl Corporation, and NAPCA. Each vehicle was required to undergo a four hour soak period prior to testing, while the test itself required almost another hour. Cars were displayed at the University of Michigan campus that same evening and race participants were presented with a buffet dinner sponsored by the Ford Motor Co. Dorm facilities for the night were also located at the University of Michigan.

The 400 mile third leg from Ann Arbor, Michigan, to Champaign, Illinois, began the CACR two-day fuel economy run. This testing constituted a distinct factor in overall scoring, and has been discussed thoroughly in Chapter IV. Race vehicles were displayed at the University of Illinois campus that evening where the race cavalcade bedded down for the night.

August 27 marked the longest leg of race passage. The more than 650 miles to Oklahoma City proved a rugged test for all vehicles still in the competition. A reception provided by the Oklahoma City Chamber of Commerce at the impressive Cowboy Hall of Fame greeted the CACR entrants at the end of that long day. Garage facilities for making minor vehicle repairs were made available at Classic Motors Incorporated. After feasting on buffalo meat and being entertained at the Hall of Fame, teams spent the night at Central State College located ten miles away in Edmond, Oklahoma.

The fifth leg of the race, 526 miles in length, terminated in Odessa, Texas. Heat was becoming a critial factor as seasonal temperatures soared above 100°. The Odessa Chuck Wagon Gang, in conjunction with the local Chamber of Commerce, hosted the CACR to a hospitable evening full of entertainment and relaxation. The race vehicles attracted many spectators to the Odessa City Hall where the cars were displayed. Overnight accomodations were in area motels due to a lack of college dormatory facilities.

On August 29th, the race pack departed Odessa bound for Tucson, Arizona. A Clean Air Car Race day had been declared when the majority of vehicles arrived in Tucson. Large crowds and a tasty barbeque offered by the Tucson Chamber of Commerce helped to lift the spirits of the exhausted CACR teams. Race cars were exhibited at the University of Arizona campus where sleeping accomodations had also been arranged.

The final leg of the race extended 537 miles through the Arizona and California deserts, over the California coastal mountains, and finally up the coast from San Diego to Pasadena, the home of the Caltech campus. Entrants were greeted at the finish line by a crowd of television and newspaper reporters in addition to the Rose Bowl Queen. The media had covered the race on both national and local networks for the entirety of the 3600 mile route with the end of the race climaxing the news coverage activity. Film crews from two different firms had recorded the seven day journey on over one hundred twenty-five thousand feet of film to be used in producing special documentaries on the event. Needless to say, all race participants were pleased with the national attention they had drawn in their crusade for cleaner air.

To present the race as a smooth-functioning event for all entrants would be misleading. No one team was free of difficulty; problems encountered were human as well as mechanical. Fatigue was a major problem as the majority of cross-country legs took twelve to fifteen hours to complete. Navigational errors often extended this time as did vehicular malfunctions. The high degree of cooperation among all parties involved helped to resolve many of the difficulties incurred.

Many examples of these problems can easily be recounted. The University of Toronto entry lost a tailpipe and muffler while backing up over debris on the ground in the University of Toronto stadium. In addition, the Toronto team threw a connecting rod just outside of St. Louis and had to rebuild half the engine. The University of Berkeley entry discovered a loss of compression in its engine due to ring seizure when attempting to leave Ann Arbor on the morning of the third leg. This necessitated the installation of an entirely rebuilt engine. The Worcester Polytechnic hybrid-electric experienced over-heating problems and had to devise a makeshift air scoop scheme to cool the electric motor. The M.I.T. turbine continually suffered from clogged fuel line filters. The M.I.T. hybrid-electric sustained a burned out alternator on the first leg and a burned out motor on the fourth leg due to mechanical component failures, and were utimatley forced to withdraw from the competition. All teams using LPG fuel discovered that compressor oil had infiltrated many of the refueling tanks. In addition, some of the designated LPG refueling facilities contained butane instead of propane which caused extreme difficulties due to inherent pressure storage differences. In retrospect, it is amazing that 85% of all vehicles which started the race arrived, intact, in California.

ACTIVITIES AT CALTECH

Post-race activities at Caltech extended from August 31st to September 3d. For exhibition purposes, all entrants as they arrived in Pasadena were parked along Caltech's rustic Olive Walk. A Clean Air Car Race parade was held on September 2d which toured through Pasadena and was greeted by the city mayor.

While at Caltech the entrant teams underwent a final hot-start emissions test. The results of this test were combined with the earlier M.I.T. hot start test to provide a deterioration factor for overall vehicular emissions. Teams were also given a chance to discuss complaints or protests with the organization committee and at the same time penalties for rule infractions were dealt out. Other committee activities included the final tabulation of race scores.

A final awards banquet was held on the evening of September 2d for all CACR participants and trophies were presented to the five class winners and the overall winner. The overall winner was selected by an impartial board of judges chaired by Dr. David Ragone, Dean of the Thayer School of Engineering. Other members included: William Gouse, a member of the President's Office of Science and Technology; John Brogan, Director, Division of Motor Vehicle Research and Development, NAPCA; Harry Barr, President, Society of Automotive Engineers, and John Maga, Executive Secretary, California Air Resources Board. A final seminar was conducted on September 3d and was chaired by Dr. Haagen-Schmidt of the California Air Resources Board. The seminar, held at the Caltech Jet Propulsion Laboratory, offered a platform for the judging panel to present their reasons for choosing the Wayne State University ICE-powered Capri as the overall winner.

WINDING UP COMMITTEE ACTIVITY

Following the post-race seminar at the Jet Propulsion Laboratory in Pasadena, committee members returned to the Boston area via a number of routes. While some flew back for the start of school activities, others vacationed in California before starting the journey home. By late September, the committee had reconvened at M.I.T. to begin its final work.

Three self-assigned tasks remained for the committee's attention. The NAPCA documentation contract had to be fulfilled. A presentation format had to be devised for the purpose of disseminating general public information. Finally, an overall evaluation of the event had to be made. Since all of the committee except for Bob McGregor, Bill Charles, and Diane Lentz had returned to academic curricula, work was assigned principally on a part-time basis.

The written documentation containing a summary report of the event was to be prepared by the committee. Bob McGregor assigned separate segments of the report to various committeemen with the deadline for completion being mid December. Editing would then require another month before publishing the document.

The committee's job with regard to the films was to serve in an advisory capacity. The most difficult aspect of this task proved to be educating the film producers on the subject of automotive air pollution. After long delays and several editing sessions, both the technical and general films were completed in late January of 1971.

Craig Lentz took it upon himself to both design a suitable presentation on CACR activity and stimulate widespread national interest in what the CACR had accomplished. With Steve McGregor's help, he put together a general information slide show and devised a format for the presentations, which were then offered at no cost to schools, civic groups, and other associations. During the following six months, more than fifty such presentations were made in all parts of the country.

Evaluating the results of the race proved to be a difficult job. The committee, the judges, industry and government representatives, as well as interested race participants all took part in the process. As a result, several major criticisms regarding the organization of the event were brought forth.

The most frequent comment centered upon the ambiguity of the test data, particulary the exhaust emission measurements. Although seven of the race vehicles had bettered the proposed 1975 Federal standards using the CACR test procedure, a definite conclusion as to whether or not these vehicles could meet the standards using the appropriate Federal test cycle procedure was impossible using available test data. Any public misconceptions were practically unavoidable since at least some knowledge of the field would have been necessary to understand the difference in test procedures.

The entrants made only one major criticism of the committee. They felt that the failure to compile a final set of rules at an early date caused innumerable problems in building and modifying the test vehicles. Once again, the principal cause of this problem was lack of time. The committee had been as ambitious as possible despite limitations of available funds and facilities. Most of the late rule changes were due to the committee's realization that earlier plans would be impossible to carry out. In addition, the committee constantly tried to avoid an authoritarian structure by incorporating all useful feedback from entrants into general CACR activities.

From within, the committee's organizational structure often seemed chaotic. Many administrative tasks did not fall into any one area of responsibility, often resulting in dual efforts or a delay of any positive action. A pyramidal structure of clearly defined areas of responsibility might have been more efficient, but it would have lacked a certain element of cooperation among committee members. The lateral organizational structure employed, in which everyone had an almost equal voice in planning, was at times inefficient, but it avoided the authoritarianism which can stifle a highly-motivated student effort.

In spite of these and other criticisms, the Clean Air Car Race must be termed a success from an organizational point of view. It started with two professors who had an idea and ended with 300 people and 150 vehicles travelling a 3600 mile transcontinental route in seven days. The phenomenal growth which it experienced and which caused so many problems is a testimony to the importance of the problem which it attacked.

OFFICIAL RULES

1970 CLEAN AIR CAR RACE

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This publication shall be the official and sole source of rules for the 1970 Clean Air Car Race. Any revision, modification, or delineation of the rules contained herein, will be announced in writing by the Clean Air Car Race Organization Committee.

It is the responsibility of each participant in the CACR to become familiar with the Official Rules.

The exact course to be followed covers 3,562 miles and is described in the CACR publication ROUTE GUIDE. One copy of the ROUTE GUIDE will be distributed to all entrant teams prior to departure.

* * * *

CLEAN AIR CAR RACE ORGANIZATION COMMITTEE

Massachusetts Institute of Technology (MIT)

California Institute of Technology (Caltech)

1970

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OFFICIAL RULES

I. OBJECTIVES

A. ASSESS VEHICLE TECHNOLOGY -- To assess the state of vehicle technology; specifically, research, and development efforts in educational institutions, industry, and government must be ascertained and publicized.

B. DETERMINE EMISSION CHARACTERISTICS -- To determine pollution emission *characteristics for modified conventional and evolutionary propulsion* systems.

C. PUBLISH TECHNICAL REPORTS -- To publish technical reports and data on vehicle technology and pollution emission characteristics respectively in a compact document which delineates the present status of automotive technology.

D. CREATE PUBLIC AWARENESS -- To create public awareness of current progress in vehicle propulsion plant development and dispel any public misconception of present engineering capabilities.

I. SCOPE

A. CONSISTENCY -- All events connected with the CACR, and all pre-race qualificiation and other activities, and all activities connected with the dissemination of information about the Race and Race entrants, shall occur only in a manner consistent with the rules stated herein.

B. RESPONSIBILITIES -- Prior to the CACR, all administrative and judicial authority shall be vested totally in a committee, to be known as the CACR Organization Committee ("the Committee"). The responsibilities and duties of the Committee shall include the following:

1. PRE-RACE

   a. The Committee shall be the sole authority responsible for the modification, promulgation, and interpretation of these rules.

   b. The Committee shall be sole source of waivers for entrants, subject to the restrictions in Section II. C.

   c. The Committee shall provide properly trained and qualified observers for the CACR; these observers shall act on behalf of the Committee during the Race, provided, however, that all such decisions may be subject to review by the Committee upon request by the entrant teams (ref: Section IV. G.).

   d. The Committee shall have full and final responsibility for handling any and all such matters which may, in the normal course of events, arise and have a bearing on the CACR.

2. RACE-EXECUTION

   a. The Committee shall be the sole authority responsible for assuring continued compliance with these rules and adjudicating any disputes arising under them.

   b. The Committee shall collect and verify any data compiled concerning CACR vehicles and participants.

   c. The Committee shall provide for and operate the Race Information Center (RIC).

   d. The Commitee shall continue to have full and final responsibility for handling any and all such matters which may, in the normal course of events, arise and have a bearing on the CACR.

3. POST-RACE

   a. The Committee shall select, using the criteria defined and discussed in Section VI, a winner in each vehicle class, as defined in Section III. A.

b. The Committee will summarize all the data collected and bear sole authority for publishing or making available in some other graphic form the official reports of the CACR.

c. The Committee shall serve as the base organization for the administration of any future CACR event.

C. WAIVER REQUESTS -- The Committee has final jurisdiction in accepting or rejecting any entry. Groups who discover that their vehicle does not meet the CACR requirements listed in Sections II. B. and II. C should write to the Committee for special consideration. The Committee is empowered to waive minor discrepancies from these rules, provided: 1) the entrant provides satisfactory evidence that a substantial effort was made to comply with the rule in question; and 2) no such waiver may be granted which would adversely affect compliance with the following Sections: II. B. 2 - II. B. 4.

D. REQUEST PROCEDURE -- Any group wishing the Committee to consider a request for special consideration should notify the Committee in writing of the particular ruling involved and the full details of efforts made to comply with the ruling. The group should then indicate the reasons why compliance is not possible. The Committee, upon receipt of such a request, shall determine the action to be taken, and notify the group involved in writing.

E. FURTHER REQUESTS -- While the decision of the Committee is final, the availability of new and pertinent information regarding a situation, may be considered sufficient reason for a further request for special consideration. No more than three such requests concerning the same point may be brought to the Committee by a single entrant group.

F. LIABILITY -- The Committee cannot be held liable for any incidents which befall an entry group participating voluntarily in the CACR.

G. CLASS WINNER -- In each competitive class (described in Section III. A) a winner will be determined using the scoring system described in Section VI. Suitable trophies will be awarded by the Committee at termination point.

H. OVERALL WINNER -- The Committee will select a panel of five individuals generally recognized to be experts in the area of automotive pollution and technology. This panel will, using the information gathered by the Committee and their own personal experience, select one entrant felt to be outstanding in all vital characteristics and to be designated as the overall winner.

III. QUALIFICATION REQUIREMENTS

A. CLASSIFICATION -- Each vehicle participating in the race will be classified by class and category, as follows:

1. CLASS -- The Committee shall place each entry in one of the following classes. Placement is based on fuel and power plant description as provided by the entrant in his final registration.

Class I: Internal Combustion Engine (ICE) - includes all types of fuels such as gasoline, LNG, LPG, etc.

Class II: Rankine Cycle - external combustion with heat transfer taking place to the working fluid; examples include steam piston and Stirling engines.

Class III: Brayton Cycle - gas turbine which includes a variety of possible working fluids.

Class IV: Electric - battery is the primary energy source; recharging occurs through off-board facilities such as charging stations.

Class V: Hybrid Electric - battery is coupled to a separate on-board energy source (such as a piston engine) which accomplishes the recharging function.

Class VI: Miscellaneous - novel power plants which do not fall into any of the first five categories. This class contains any vehicle which cannot be reasonably placed in one of the other classes.

2. CATEGORIES -- Vehicles participating in this Race will be considered in three categories:

a. Committee vehicles, consisting of those vehicles being operated by members of the Committee.

b. Entrant vehicles, consisting of those vehicles which are entered in the Race, and upon which all measurements will be made and tests performed.

c. Trail vehicles, consisting of those vehicles which are entered in the Race for the purpose of carrying additional personnel, equipment, fuel, etc. and acting in a support capacity for the entrant vehicles.

B. VEHICLE QUALIFICATION -- Each vehicle must meet the following standards in order to participate as an entry in the CACR:

1. STRUCTURAL STANDARDS -- Each vehicle must satisfy the following:

a. Must have a minimum of four wheels.

b. Must have a fully-enclosed passanger compartment with minimum capacity of two adult passengers.

c. Must satisfy all inspection and registration requirements prescribed by the state in which the vehicle has been developed and tested and present documentary evidence of this to the Committee. Entrants other than U.S. entrants must meet the Massachusetts State Standards.

d. Must satisfy any additional requirements imposed by the Federal Government, since cross-country travel will take place on the Interstate Highway System. No such requirements have been stipulated at present.

2. <u>POLLUTION EMISSION STANDARDS</u> -- Documentary evidence must be submitted to the Committee by 16 August 1970, which certifies that the vehicle's exhaust complies with the 1975 Federal Standards for acceptable levels of pollution emission. If propulsion is such that there is no exhaust (e.g. vehicle is in Class IV), then the vehicle will be deemed to have met this requirement for registration purposes.

3. <u>PERFORMANCE STANDARDS</u> -- Each entrant vehicle must meet the following performance standards:

   a. Acceleration: from 0 to 45 mph within 15 seconds.

   b. Range: Travel 60 miles within 90 min. on a level road without refueling or recharging.

4. <u>SAFETY STANDARDS</u> -- Each entrant vehicle must meet the following performance standards:

   a. Code of Federal Regulations, Title 49, Chapter 3, Part 371, Subpart b. Any additional safety standards required by the state in which the vehicle is registered and inspected must also be met.

   b. All vehicles are expected to meet any additional requirements imposed by the Federal Government, since travel will occur on the Interstate Highway System. Such requirements include special permits and standards for transporting hazardous fuels.

5. <u>IDENTIFICATION STANDARDS</u> -- On every vehicle entered in the CACR, the following areas are designated for the exclusive use of the Committee:

   a. On the front side panel of both sides of each vehicle, an area approximately nine inches square shall be reserved for an entrant number to be assigned.

b. The front door, on both sides of the vehicle, in its entirety shall be reserved for vehicle identification and indication of Race participation. Such material shall be specified and provided by the Committee.

c. A portion of the rear side panel, on both sides of the vehicle, shall have placed upon it the name of the educational institution affiliated with the vehicle. This name should be displayed in block letters; size and coloring of lettering shall be at the discretion of the entrant.

6. APPEARANCE STANDARDS -- The Committee will require that any other decorations, painting, or commercial messages follow these guidelines:

   a. Said decoration, painting, or message should occupy a limited area, must be in good taste, and cannot interfere with the areas described in Section III.B.5.

   b. Any lettering used in the non-reserved areas must be smaller in size that the lettering used in placing the name of the educational institution on the rear side panels.

   c. Vehicles not meeting these standards may not participate in the CACR unless they can show, to the satisfaction of the Committee, that the vehicle identification and painting was done prior to the promulgation of a definite ruling in this area (i.e., prior to 24 June 1970); and the cost of correcting the situation is prohibitive and would necessitate the withdrawal of the vehicle from the Race. The Committee is hereby empowered to adjudge vehicles under this regulation and execute its provision.

C. PARTICIPANT QUALIFICATION -- Entrant team members must meet the following standards in order to participate in the CACR:

1. TEAM AFFILIATION -- All entry groups must be registered with the Committee under the name of an educational institution. A letter certifying this relationship between the entry and the school must come from the respective school's Dean of Engineering or President (one for each entrant). In the case of high schools, this letter should come from the administrative head or principal of the school.

2. INDIVIDUAL AFFILIATION -- All participants must affiliate with an educational institution to the extent that the conditions stated in Section III.C are satisfied. Should this prove difficult or impossible, immediately contact

the Committee so that they may give special consideration to the situation.

3. ENTRANT TEAM DIVISION -- All personnel officially affiliated with a team must be designated as either part of the driving team or the techanical team. These will be the only people authorized to operate within or on the vehicle in any official capacity or to represent the team in any actions or decision which may be necessary.

4. DRIVING TEAM -- The driving team, containg not more than four nor less than two members, each of whom:

   a. Must be registered full time students.

   b. Must have been registered for and completed the 1970 Spring semester at their respective school, which must be accredited with the Department of Health, Education and Welfare.

   c. Must draw up and present the technical paper concerning their vehicle to the Committee and represent their respective vehicle entry group at the seminar prior to the Race.

5. TECHNICAL TEAM -- The technical team is optional and contains no limit on the number of personnel. The technical team members:

   a. May be passengers in the entrant vehicle.

   b. May give advice, but not physical assistance, to the driving team in making repairs on the road.

   c. May give advice and physical assistance to the driving team in making repairs at a designated repair station (ref: Section IV.H.2).

6. TEAM CAPTAIN -- The team captain shall be an individual designated by the entrant team from either the driving or technical team who shall:

   a. Formally represent the entrant team in any communications with the Committee.

   b. Assume responsibility for the operation of the vehicle during the CACR.

   c. Assume responsibility for the conduct of the members of the entrant team during all phases of the CACR.

d. Assume responsibility for providing the Committee with all documentation requested.

D. TECHNICAL PAPER REQUIREMENT -- Each entrant must submit a technical paper describing, in complete detail, the vehicle's total operating system. Particular emphasis should be placed on the usual aspects of the vehicle. The paper should be written in a manner appropriate for a paper to be published; the paper should describe, in sufficient detail, the vehicle power plant so that a person unfamiliar with the vehicle could understand its operating characteristics. The style and quality of photos, and other graphic materials should be those recommended by the major scientific and engineering socities.

E. ACCEPTANCE -- Upon receipt of documentation which substantiates that all of the above requirements have been met, the Committee will notify the entrant of his acceptance.

IV. RACE CONTROL

A. OBJECTIVES -- The objectives of Race Control shall be:

1. DRIVING TIME -- Compile the accurate elapsed driving time for each entrant for each leg of the Race (ref: Section IV.I).

2. ENERGY CONSUMPTION -- Compile data from each entrant concerning total energy consumed during each leg of the Race.

3. VEHICLE LOCATION -- Locate the approximate position of each vehicle at anytime during the Race.

4. RULE ENFORCEMENT -- Assure that each entrant abides by the Official Rules set forth by the Committee and stated herein with any subsequent modifications.

B. RACE ROUTE -- A detailed description of the Race Route will be be given all entrants prior to the Race. This publication shall be entitled the ROUTE GUIDE and will include maps, itineraries, and general impound information for each leg of the Race.

C. DRIVERS -- Only those persons on the entrant team who have previously been designated as members of the driving team (ref: Section III. C.4) will be allowed to operate the vehicle during the Race leg. Upon completion of the leg, any member of the entrant team may operate the vehicle.

D. OBSERVERS -- The Committee will select and instruct a group of qualified observers. Committee control shall operate as follows:

1. ASSIGNMENTS -- An observer is to be assigned to an entrant by the Committee during the evening prior to that leg in which he will be observing.

2. DISINTERESTED PARTY -- An observer must be a disinterested party to the entrant to which he is assigned.

3. SINGLE LEG -- An observer will not be assigned to the same entrant for more than one leg of the Race.

4. CHANGES -- An observer's assignment may be changed by the Committee at any time.

E. OBSERVER RESPONSIBILITIES -- The observers are responsible for diligently observing at all times the actions and conditions under which the vehicle to which they are assigned is operating and for accurately recording all required data on the Observer's Report. The responsibility of the observer during the time in which he is assigned to an entrant vehicle includes the following:

1. The observer must sit in the entrant vehicle to which he has been assigned.

2. The observer must remain with the vehicle to which he has been assigned until he has been relieved or replaced.

3. The observer must have a reliable watch with a sweep second hand.

4. The observer may not assist drivers in any way except in an emergency (i.e. an accident).

5. The observer must record all data in detail on the Observer's Report and must supply all pertinent information requested including reports on any traffic violations. Whenever an an entry is made, the time and odometer reading must be recorded.

6. The observer must submit the Observer's Report to a designated Committeeman at the impound (ref: Section IV.F.1).

7. The observer must not interpret rules for participants, and cannot say what work may or may not be done on entrant vehicles, their duties being only to record required data and to notify drivers of violations of traffic laws and regulations (ref: Section IV.K.).

8. The observer must not attempt to interpret the ROUTE GUIDE nor in any way comment on the navigation of the entrant vehicle.

9. The observer must telephone the Race Information Center and report the location and status of the entrant to which he has been assigned, according to a call-in schedule to be determined and posted by the Committee.

10. In addition to the surveillance of the cars in which they are riding, observers shall be expected, insofar as possible to make note of any other entrant vehicle which may be laid up alongside the road and to note the extent of the work being done upon it. Reports should show time, entrant number of the car involved, and the odometer reading of the car in which the observer is riding.

11. The observer must report to his assigned vehicle 20 minutes prior to scheduled departure time. At this time, he must make appropriate entries on the Observer's Report. These entries will include entrant number, driver's names, odometer reading and other facts that can be determined at at this time.

F. IMPOUNDS -- All entrant vehicles are required to be parked in the Official CACR Impounds during the period August 16 thru September 2, 1970. The Impounds for the evenings of August 24-29 shall be designated Route Impounds. The following conditions will exist at the Route Impounds:

1. CHECK-IN POINT -- The Mobile Headquarters Van (MHV) will be the official Impound Check-In Point. Observers will turn in their Observer's Report to a designated Committeeman at the MHV upon their arrival at the Impound.

2. PARKING -- A Committeeman will direct the entrant vehicle to a suitable parking location upon its arrival.

3. PUBLIC DISPLAY -- The vehicles will be open for public display at the Impound during the evening. Specific hours will be posted by the Committee. Each entrant team is required to have a minimum of one team member present at the vehicle for the purposes of publicity and information.

4. SECURITY -- The Committee will provide night security for all entrant vehicles at the Impounds.

5. SCORES -- Legs and cumulative scores for each entrant will be posted at the Impound.

6. DEPARTURE TIMES -- Departure times and observer assignments will be posted for the next leg at the Impound.

7. BULLETINS -- Bulletins and official rules modifications will be posted at the Impound. It will be the responsibility of the entrant or his representative to read and comply with same.

8. DEPARTURE -- Departure of all entrant vehicles will occur from the Impound area and be under the direction of a designated Committeeman.

G. PROTESTS -- At any convenient time enroute, the Observer's Report may be inspected by the Team Captain. Should any objection to the Observer's Report arise, the observer must report such objection to a designated Committeeman at the Impound Check-In point. In the event of a dispute as to facts, the Committeeman may require such persons to state their objections in writing.
Immediately following each leg, a panel from the Committee will meet. At that time the Team Captain or his representative must register any protest pertaining to that leg and submit proof in support thereof.
The Committee will hear only protests registered on the leg just completed.

H. REPAIRS -- Repairs to the entrant vehicle will occur at either of the following locations:

1. "ON THE ROAD" -- Should the vehicle become disabled while on the race route, only those members designated previously as on the driving team (ref: Section II.C.4) may physically repair the vehicle. Repair "On the Road" will mean any repair which can be made by the driving team alone at the point where the vehicle disabled.

2. "REPAIR STATION" -- Should the vehicle become disabled to the extent that a repair "On the Road" is not possible, it may be towed or otherwise moved to the nearest "Repair Station". The "Repair Station" must be approved by the observer as a facility in which major repairs may be performed on automobiles. Any members of the entrant team may perform repairs at the approved "Repair Station".

I. ELAPSED DRIVING TIME (EDT) -- The score for each leg of the Race will be determined by the "Elapsed Driving Time." The "Elapsed Driving Time" will be defined as the time taken by the vehicle in completing the leg. This time includes all refueling, repair, and all other time which was used to maintain the vehicle during that leg.

1. DEFINITION -- The "Elapsed Driving Time" will be calculated as follows:

$$EDT = TDT - MIN (ABT, NBT) - TO$$

Where: TDT = Total Driving Time, defined as the straight difference between departure and arrival times without corrections.

ABT = Actual Break Time, defined as the meal and break time total as recorded by the observer.

NBT = Normalized Break Time. A calculation based on 45 minutes per meal and 8 minutes for every hour or fraction thereof taken in the total driving time.

TO = Time Outs. Defined in Section IV.J.

2. PROCEDURE -- All time will be noted from the observer's watch (as required in Section IV.E.3). The observer will synchronize his watch with the Committeeman responsible for departure. The observer will in no way reset his watch following this synchronization. This rule includes time zone crossings.

J. TIME OUTS -- Only under extenuating circumstances will a "Time Out" be called and noted by the observer. In such an instance, the time so taken will not be charged against the EDT of the entrant vehicle.
During a "Time Out" the vehicle must be completely stopped. No maintainance or repair work may be performed on the vehicle during the "Time Out".
"Time Outs" will only be granted for the following reasons:

1. REFUELING -- A delay at the refueling station or facility. The "Time Out" will be from the time the car comes to a complete stop until the time the refueling facilities become available. During the actual refueling, the time is credited towards the EDT.

2. EMERGENCY -- A necessary delay at a point on route caused by a condition beyond the control of the entrant. Specifically this does not include traffic congestion on the Race route.

3. PERSONAL INJURY -- A delay caused by personal injury to a member of the entrant team, or to a third party as a result of the entrant's personnel or vehicles. Such injury and circumstances will be noted in the Observer's Report.

4. PROPERTY DAMAGE -- A delay caused by damage to an entrant vehicle by a third party, or to a third party by an entrant vehicle. This includes damage that may occur between entrant vehicles on the same team. Such damage and circumstances will be noted on the Observer's Report.

5. OBSERVER COMMAND -- The observer may demand the entrant vehicle to be stopped at any time if, in his opinion, the continuation of the vehicle would be unsafe for other than mechanical reasons. This shall include the areas of driver fatigue and adverse weather conditions.

K. TRAFFIC REGULATIONS -- The Committee requires strict adherence to all traffic laws and regulations in all states, cities and towns. Observers must report length of time, distance, place and road conditions when and if any flagrant infraction of this rule occurs. An entrant violating this rule will be penalized if, in the opinion of the Committee, the law was flagrantly violated.

L. DRIVING FORMATION -- The entrant's test vehicle must precede all other vehicles on the team. At no time or place during the route may any car be used as a pace car, be lettered or painted similar to an entrant vehicle or be so driven as to interfere with the operation of any other vehicle.

M. WITHDRAWAL -- It shall be the duty of the observer under all conditions to remain with the entrant vehicle (ref; Section IV.E.2) or until the Team Captain officially announces withdrawal from the CACR. In such a case, the Team Captain must sign the Observer's Report at the designated location.

V. MEASUREMENTS

A. SCOPE -- Several tests pertaining to a determination of each entrant vehicle's operating characteristics include the following:

1.) Exhaust emissions tests
2.) Vehicle performance tests
3.) Entrant qualification test
4.) Vehicle endurance test
5.) Other requirements

This section defines measurement techniques to be employed in conducting the above-stated tests.

B. EXHAUST EMISSIONS TESTING -- This part outlines the cold start test cycle procedure to be used for vehicles entered in Class I, II, III, and IV.

1. ICE, Steam, and Gas Turbine Vehicle Test Procedure

a. SETUP -- To the empty weight of the fully fueled vehicle will be added a 300 pound allowance for passenger weight. The resulting weight will be used to set the dynamometer inertia wheel and power absorption unit via the following tables:

Loaded Vehicle Weight (pounds)	Equivalent Inertia Weight (pounds)
Up to 1625	1500
1626 to 1875	1750
1876 to 2125	2000
2126 to 2375	2250
2376 to 2625	2500
2626 to 2875	2750
2876 to 3250	3000
3251 to 3750	3500
3751 to 4250	4000
4251 to 4750	4500
4751 to 5250	5000
5251 to 6000	5500

Loaded Vehicle Weight (pounds)	Power Absorption Unit Setting (hp)
Up to 2750	4
2751 to 4250	8
4251 to 6000	10

In order that no tire damage occur during the test, tires will be inflated to 45 psig. The vehicle, which must have been in a power-down state for the previous four hours, will then be pushed onto the dynamometer ; and the exhaust sample line will be attached. A fan will be positioned at the front of the vehicle to maintain engine cooling.

b. OPERATING PROCEDURE -- The vehicle will be started on the dynamometer according to the entrants recommended starting procedure. It will then be driven nine times through the following driving cycle:

Sequence Number	Mode	Acceloration (mph/sec)	Time In Mode (sec)	Cumulative Time (sec)
1	Idle	0	20	20
2	0-25	2.2	11.5	31.5
3	25-30	2.2	2.5	34
4	30	0	15	49
5	30-15	-1.4	11	60
6	15	0	15	75
7	15-30	1.2	12.5	87.5
8	30-50	1.2	16.5	104
9	50-20	-1.2	25	129
10	20-0	-2.5	8	137

Vehicles with automatic transmissions will be driven in "drive". Other vehicles will be shifted at speeds recommended by the entrant. If no such speeds are supplied, shifting will be at 15mph, 25mph, and (if applicable) 40mph.

c. HANDLING OF EXCEPTIONAL CIRCUMSTANCES

(i) If the vehicle cannot accelerate at the specified rates, then it will be run at wide open throttle until vehicle speed reaches the speed it would be during the time of the test. Whenever vehicle acceleration lags more than 3 seconds behind the trace, the trace will be stopped until the vehicle has a chance to catch up. Vehicles not capable of meeting the 50mph maximum speed will be accelerated to 45mph and continued for 9 seconds at wide open throttle before the trace is restarted.

(ii) If the vehicle will not start within a "reasonable" time (10 seconds unless otherwise specified by the competitor) the test will be shut down. If the failure to start was an operational error, the vehicle will be rescheduled for testing from a cold start. If the failure was caused by vehicle malfunction, corrective action of less than 30 minutes duration may be taken, and the test continued. If corrective action is unsuccessful, the test will be aborted. Otherwise, sampling systems will be reactivated at the same time the start up sequence is initiated.

(iii) If the engine false starts, the operator will repeat recommended starting procedure. If the engine stalls during an idle period, the engine will be restarted soon enough to allow the vehicle to follow the next acceleration, the driving schedule indicator will be stopped; when the vehicle restarts the driving schedule indicator will be reactivated. If the engine stalls during some mode other than idle, the driving schedule indicator will be stopped; the vehicle restarted, accelerated to the required speed; and the test continued. If the vehicle will not restart within one minute, the test will be aborted.

d. SAMPLING SYSTEM

(i) Internal Combustion Engines -- Constant Volume Sampling (CVS) will be used for vehicles with ICE's. In this system, all of the exhaust is collected and diluted with enough air so that a constant volume flow rate is maintained. A portion of the dilute mixture will be drawn off at a constant flow rate and collected in a bag. Dilution air will be sampled similarly. The pollutants in the bag will be analyzed within 10 minutes after the completion of the test. In addition, the raw exhaust may be continuously sampled, with the exhaust of the continuous analysis cart fed into the inlet of the constant volume sampler.

(ii) Steam and Gas Turbine Vehicles -- If the exhaust volume flow is low enough, constant volume sampling will be employed. Otherwise raw exhaust will be monitored continuously, including temperature. In both cases, fuel flow rate will be continuously monitored.

e. CALCULATIONS

(i) CVS -- Total exhaust volume (V_{mix}) will be determined from the number of revolutions of the positive displacement pump. This will be corrected to 528 degreesR and 760mm Hg. The final grams-per-mile figure for each pollutant will be determined through the following formulae:

Where: P is density
C is concentration in ppm
K is concentration in per cent
E is emission in grams per mile
d is the distance driven in nine repititions of the driving cycle

$$E_{HC} = \frac{V_{MIX} \cdot P_{HC} \cdot C_{HC} \cdot 10^{-6}}{d}$$

$$E_{CO} = \frac{V_{MIX} \cdot P_{CO} \cdot K_{CO} \cdot 10^{-2}}{d}$$

$$E_{NO} = \frac{V_{MIX} \cdot P_{NO} \cdot C_{NO} \cdot 10^{-6}}{d}$$

(ii) Continuous Sampling -- For each mode, an average fuel flow rate will be measured, and converted to an average carbon atom flow rate (in moles per second). The average HC, CO, and CO_2 reading for each mole will be converted to mole percent, and added. The average flow rate for each mode is then $R=\frac{F}{S}$ where F is the fuel flow rate in moles carbon/seconds and S is the sum mole percent of HC, CO, and CO_2. For each mole R is then converted to R_V, a volume flow rate by 1) converting to 528 degrees R and 760 mm Hg; 2) multiplying by a constant to convert from moles/sec. to cubic feet/ sec.. Pollutant mass M for mole i and pollutant K is then:

$$M_{K,i} = R_{Vi} \cdot t_i \cdot C_K \cdot P_K$$

Where t_i is the time spent in mode i, and P_K is the density of pollutant K. The $M_{K,i}$ are summed over the 10 modes and nine repititions of the driving cycle divided by the distance traveled over nine cycles. This gives the final grams per mile figure for each pollutant.

2. HYBRID - ELECTRICS

a. SETUP -- The setup will be identical to that described in Section V.B.1.a.

b. OPERATING PROCEDURE -- The vehicle will be run at a constant speed of 50mph for 10 minutes. The on-board charging source will remain on throughout this period.

c. SAMPLING -- Constant Volume Sampling will be employed.

d. CALCULATIONS -- Test values will be converted to grams of pollutant per unit of fuel. Fuel consumption will be taken over the length of the race. The final grams per mile figure will be found by multiplying fuel consumption by the grams of pollutant per unit of fuel and dividing by the total miles traveled.

C. VEHICLE PERFORMANCE TESTING -- Four specific tests will be conducted by the Committee to determine the entrant vehicle's performance characteristics for scoring purposes.

1. BRAKING -- The entrant vehicle braking time and distance will be measured and recorded for two controlled stop situations:
   a) 30mph to full stop; and
   b) 60mph to full stop

   The test will be conducted by running each entrant vehicle in a 12 foot wide lane demarcated by pylons on a level roadway. The test must be run a minimum of two times for each controlled stop situation. If any pylons are knocked over during the controlled stop, brakes may be adjusted and the test must be repeated. If the entrant vehicle fails to complete the test on more than two runs, the vehicle's brakes must be repared and the entire braking test must be repeated on the following day.

2. ACCELERATION -- The entrant vehicle acceleration time and distance will be measured and recorded for three speed range situations:
   a) 0mph to 30mph
   b) 0mph to 45mph
   c) 20mph to 50mph

   A minimum of two separate test runs will be conducted for each speed range.

3. NOISE -- Noise measurements in units of dB(A) will be made on each entrant vehicle according to the test procedure specified in SAE J986a for the following driving situations:
   a) 30mph open throttle,
   b) 30mph cruising,
   c) 60mph cruising, and
   d) idle

4. URBAN DRIVING CYCLE -- This consists of a driving course layout on a paved flat surface with the route demarcated by pylons so that memory will not be necessary to remain on course. This route is designed to test entrant vehicle generalized performance and manuverability by simulating an urban driving cycle trip. Included in the course layout are straight sections, corners, connecting turns, a back-up situation, and a lane change. At least three members of each entrant team are required to drive the vehicle in this event. The time each team member takes to negotiate the route will be measured and recorded by a Committee official. A vehicle safety check will be conducted by Committee officials prior to the entrant vehicle's first run on the urban driving cycle course.

D. ENTRANT QUALIFICATION TEST -- The requirements for entrant vehicle performance characteristics have been defined in Section III. Measurements will be made of the pertinent parameters associated with each requirement, and the information will be recorded in the entrant's file. The specific tests to be conducted on each entrant vehicle include the following:

1) Acceleration time and distance from 0 to 45mphi
2) Time to travel a 60 mile distance on a level roadway without refueling; highway speed limits must be obeyed during the test.

E. VEHICLE ENDURANCE TEST -- CACR cross-country travel will be considered a measure of entrant vehicle endurance and reliability. Specific parameters to be measured and recorded are the observer's responsibility and include the following:

1) Entrant vehicle fuel consumption: type of fuel and quantity thereof;
2) Entrant elapsed driving time for each leg of the CACR route;
3) Repairs, adjustments, and modifications of any type to the entrant vehicle.

This information will be recorded in the "Observer's Report" and kept in the respective entrant's file which will be maintained by the Committee. This procedure has been described in detail in Section IV.E

F. OTHER MEASUREMENTS -- Other information which will be recorded by the Committee includes the following measurements:

1) Vehicle weight
2) Vehicle passenger capacity
3) Tires: make, dimensions, and pressures
4) Traveling range without refueling or recharging

VI. SCORING

A. SCORING FORMULA -- Each vehicle shall have a score derived from the following formula:

$$S = E(P+R)$$

where:

E = emissions score
P = performance score
R = race score

The entrant obtaining the highest score in each class using the above formula shall be declared the class winner. (Ref: Section I.G.)

B. RESPONSIBILITY -- The Committee will be responsible for determining the score for each entrant, and all scores so determined will be considered final.

C. EMISSIONS SCORE -- The emissions score shall be based entirely on values obtained from the cold start test cycle procedure.

1. FORMULA -- Each vehicle in classes I, II, III, V, and VI shall have an emissions score as determined by the following formula (all variable values will be recorded in grams per mile):

$$E = \frac{1}{1/3\left[\frac{HC}{.5} + \frac{CO}{11} + \frac{NO_x}{.9}\right]}$$

where:

$$HC = \max\left[HC_{measured},\ 0.25\right]$$

$$CO = \max\left[CO_{measured},\ 4.7\right]$$

$$NO_x = \max\left[NO_{x\ measured},\ 0.4\right]$$

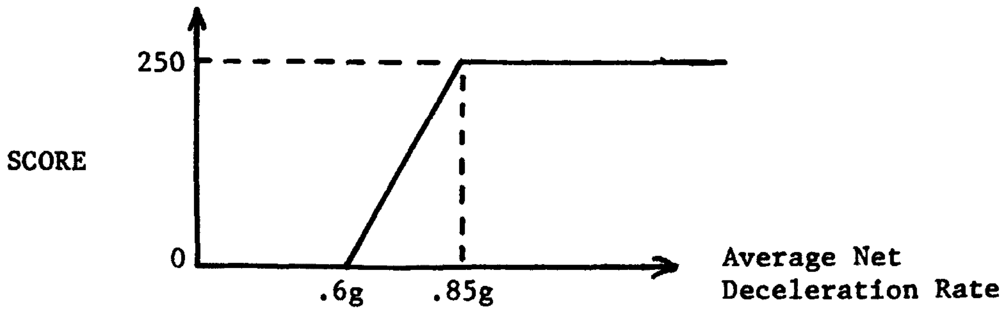
2. RANGE -- The emissions score, E, shall have a maximum formula value of 2.2.

3. BONUS -- If the vehicle tested exceeds all the proposed 1980 Federal standards on pollution emissions [HC 0.25; CO 4.7; and NO_x 0.4], the Committee shall award the entrant an emissions score value of 2.5.

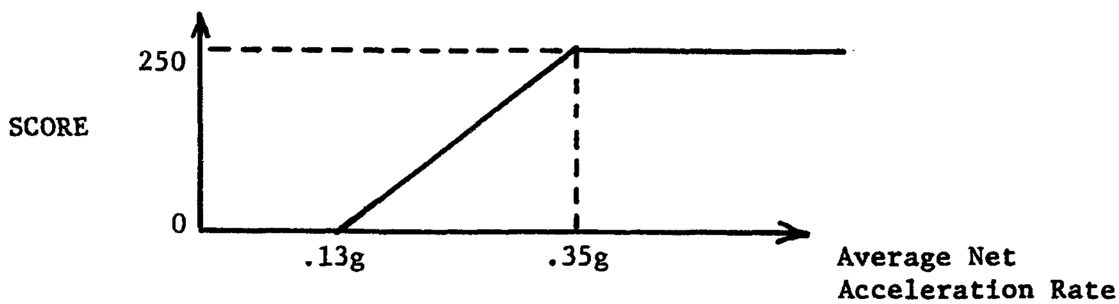
D. PERFORMANCE SCORE -- The performance shall consist of the unweighted sums of four tests.

1. SCORE DIVISION -- Scoring shall be divided into the following:

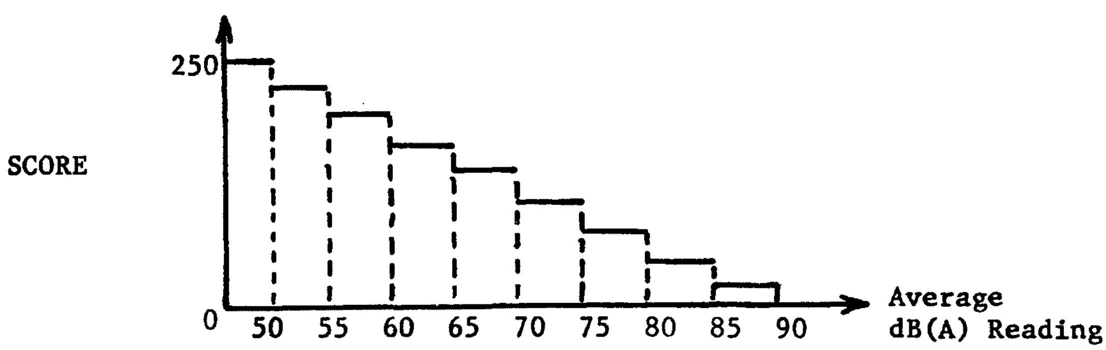
a. BRAKING TEST -- Braking distances will be measured for two controlled stop situations. Two distance measurements for each situation will be converted to respective net deceleration rates. Points will be awarded according to the following scoring curve:



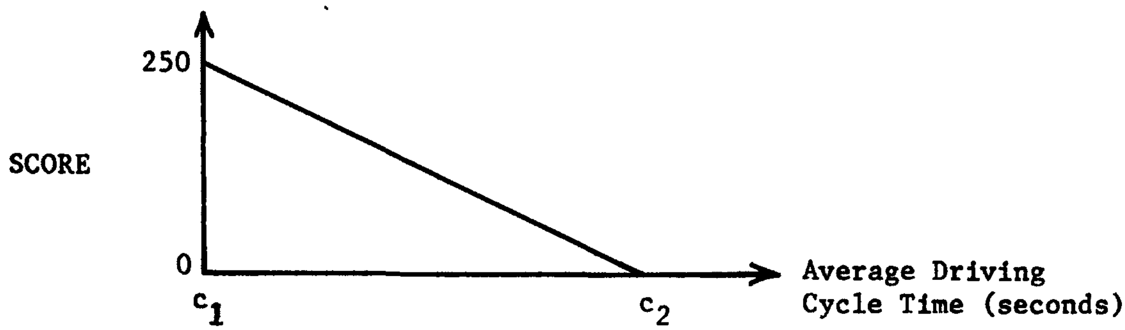
b. ACCELERATION TEST -- An average acceleration rate measurement will be made for each of the three speed ranges specified in Section V.C.2 . The three values will be averaged in an unweighted sum to compute a net average acceleration rate. Points will be awarded using the following scoring curve:



c. NOISE MEASUREMENT TEST -- The dB(A) readings recorded in the four noise measurement tests specified in Section V.C.3 will be arithmetically averaged and the final value rounded to the nearest dB(A). Points will be awarded using the scoring curve illustrated below.



d. URBAN DRIVING CYCLE EVENT -- An average driving cycle time will be computed for each entrant by determining the unweighted average of the best recorded times for each of three team members. Points will be awarded using the following scoring curve:



The constants c_1 and c_2 will respectively determine the minimum and maximum average driving cycle times and will be established by the Committee when the final driving cycle course has been set up.

2. RANGE -- The highest possible performance score value is 1000 points. The max score value for the scoring curves illustrated in the preceding section is 250. Each test, then, has a range of 0 to 250 points for scoring purposes.

E. RACE SCORE -- The race score shall be based on a comparison of the entrant elapsed driving time (Ref: Section IV.I.1) and the normalized driving time.

1. NORMALIZED DRIVING TIME -- The NDT is an unweighted average of elapsed driving times compiled by a minimum of three official Committee cars during the day in which that particular leg is driven. The determination of NDT will be as follows:

a. When the posted speed limit is 45mph or lower, the official Committee cars will travel at the speed limit.

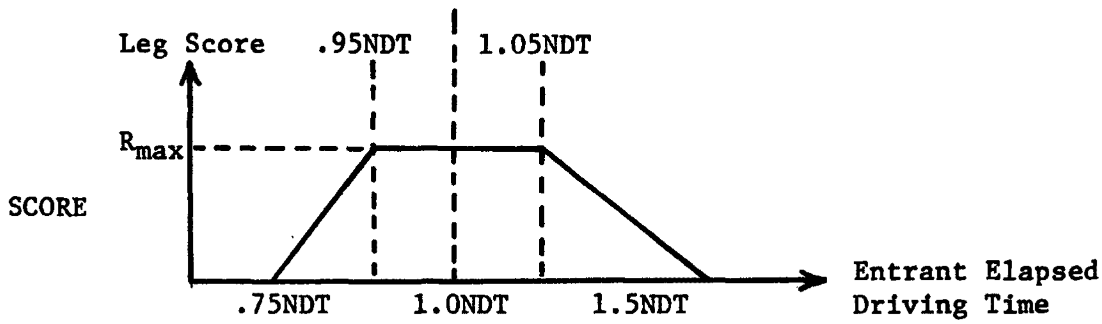
b. When the posted speed limit is 50mph or higher, the official Committee cars will travel at a speed of 5mph below the speed limit.

c. When the speed limit is not posted, the official cars will travel at a speed of 65 mph.

d. The official Committee cars will follow the traffic laws and regulations of all states, cities, and towns.

e. NDT shall include all time taken by the vehicle in completing the leg. This time includes all refueling; however, it will not include time taken, if any, for road repairs made on the official Committee cars.

2. SCORING CURVE -- Each entrant vehicle shall have its leg score determined by the following curve:



3. PENALTY -- Should the observer report a violation of either traffic laws and regulations or the CACR Official Rules, the entrant shall be penalized a percentage of his score for that leg. Penalties shall not exceed fifteen (15) percent for each violation. The penalty shall be determined by the panel hearing protests at the impound.

4. TOWING -- Should the vehicle become disabled to the extent that it must be towed (Ref. Section IV.H.2), the observer will note the actual length of time the entrant is under tow. The tow time shall be doubled for purposes of deriving the total driving time.

Upon repair, the vehicle will not be required to return to the point of breakdown, but rather may continue from the "repair station."

5. RANGE -- The highest possible race score value is 1000 points. The points will be distributed for each leg according to the percentage of total official miles in that leg.

6. DISQUALIFICATION -- The entrant is expected to complete a leg within 24 hours of his assigned departure time. (Time-outs will not be counted.) Any entrant vehicle not completing the leg in this period must be dropped from the race.

END OF OFFICIAL RULES

ADDENDA TO THE OFFICIAL RULES

The following should be added to the section of the rules as indicated:

III.B.4.c. All entrant vehicles are expected to have a portable fire extinguisher with the following capabilities:

(1) it must be easily accessible for a person sitting in the driver seat position;

(2) it must be held securely in place during periods of vehicle travel; and

(3) a dry chemical powder as recommended by Fire Departments in suggested by the Committee.

V.B.1.e.(ii) Second and third sentences should read: "The average HC, CO, and CO_2 reading for each mode will be converted to mole percent carbon atoms and added. The average flow rate for each mode is them R = F/S where F is the fuel flow rate in moles of carbon/sec. and S is the sum concentration of HC, CO, and CO_2 in terms of mole percent carbon atoms."

VI.A. Overall scoring formula should read:

$$S = E\ (P + R + FE)$$

where: FE = fuel economy score

VI.C.1 Should be entitled: EMISSIONS SCORE FOR VEHICLES IN ALL CLASSES EXCEPT CLASS IV.

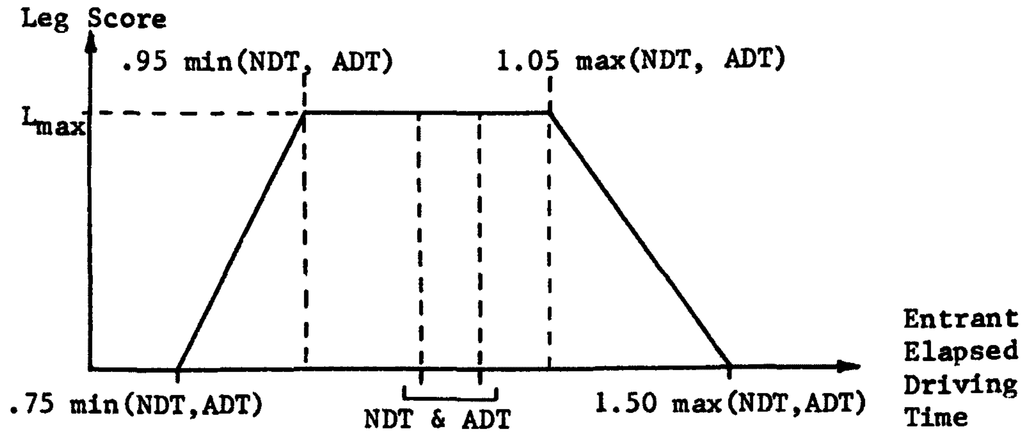
VI.C.2 EMISSIONS SCORE FOR VEHICLES IN CLASS IV -- For vehicles in class IV, the value of E shall be determined by the total power consumed over the length of the Race, i.e.,

$$E = \frac{(0.5)\ (3562)}{P_{total}}$$

where P_{total} is the power consumed recharging the vehicle on the Race, as measured in kwh by the observer.

VI.E.1.f. In addition to the NDT, the Committee will post an Announced Driving Time (ADT) for all legs prior to the Race start.

VI.E.2 Correct the scoring curve to read:



Notes: The emissions score (Rule VI.C.) was modified to account for system degragation by inserting deterioration factors. A description of the final emissions scoring procedure is found in Chapter V of this document.

A discussion of the fuel economy score after its inclusion into the overall scoring formula is found in Chapter IV of this document.

ACKNOWLEDGEMENTS

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The Clean Air Car Race Organization Committee gratefully thanks the following sponsors and contributors, without whose assistance our task would have been impossible.

Ann Arbor Chamber of Commerce
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Boston Edison Company, Boston, Massachusetts
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Call-A-Computer, Minneapolis, Minnesota
The California Institute of Technology
Central State College, Edmond, Oklahoma
The Chrysler Corporation
The City of Odessa
The City of Toronto
Classic Motors, Oklahoma City, Oklahoma
Copper Development Association, New York, New York
Cornell Aeronautical Laboratories, Buffalo, New York
Country Gas Company, Danvers, Massachusetts
Department of Transportation
Dresser Industries, Dallas, Texas
E. I. DuPont Corporation, Wilmington, Delaware
Edison Electric Institute, New York, New York
Electric Energy Conversion Corporation, New York, New York
Electric Fuel Propulsion, Ferndale, Michigan
Electric Vehicle Council, New York, New York
Engelhard Minerals and Chemicals Corporation, Newark, New Jersey
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The National Air Pollution Control Administration (APCO)
National Cowboy Hall of Fame, Oklahoma City, Oklahoma
National LP Gas Association, Chicago, Illinois
National Rural Electric Cooperative Association, Washington, D. C.

ACKNOWLEDGEMENTS (continued)

Odessa Butane Company, Odessa, Texas
Oklahoma City Chamber of Commerce
Olson Laboratories, Dearborn, Michigan
Ontario Department of Tourism and Information
Peter Fuller Cadillac-Olds, Boston, Massachusetts
Polaroid Corporation
Pyle National Company, Chicago, Illinois
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Texas Liquid Petroleum Gas Association
Tucson Chamber of Commerce
The University of Arizona
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The University of Toronto
Vernitron Corporation, Malden, Massachusetts
Westinghouse Electric Corporation
Xerox Corporation

The Organization Committee also wishes to thank the following utility companies for their efforts in constructing the Transcontinental Electric Expressway.

Arizona Public Service Company, Tucson, Arizona
Boston Edison Company, Boston, Massachusetts
Cambridge Electric Light, Cambridge, Massachusetts
Central Illinois Public, Mattoon, Illinois
Commonwealth Edison Company, Decatur, Illinois
Community Public Service Company, Fort Worth, Texas
Consumers Power, Jackson, Michigan
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Imperial Irrigation District, Imperial, California
Indiana and Michigan Electric, Benton Harbor, Michigan
Lebanon Municipal Light Department, Lebanon, Missouri
Massachusetts Electric Company, Worcester, Massachusetts
Niagara Mohawk Power, Syracuse, New York
Northern Indiana Public Service, Gary, Indiana
Oklahoma Gas and Electric Company, Oklahoma City, Oklahoma
Ontario-Hydro, Toronto, Ontario, Canada
Pasadena Municipal Light and Power Company, Pasadena, California
Public Service Company of Oklahoma, Tulsa, Oklahoma

ACKNOWLEDGEMENTS (continued)

Public Service of New Mexico, Albequerque, New Mexico
Rantoul Light and Power Department, Rantoul, Illinois
Rio Grande Electric Cooperative, Marfa, Texas
Rochester Gas & Electric, Rochester, New York
Rolla Municipal Utilities, Rolla, Missouri
San Diego Gas and Electric Company, San Diego, California
Southern California Edison Company, Los Angeles, California
Southwestern Public Service, Amarillo, Texas
Springfield City Utilities, Springfield, Missouri
Sullivan Municipal Light Department, Sullivan Missouri
Sulphur Springs Valley Electric Cooperative, Inc., Wilcox, Arizona
Texas Electric Service Company, Fort Worth, Texas
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Wellton-Mohawk Irrigation, Wellton, Arizona
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