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THE BEHAVIOUR OF THE MILITARY BATTERY TYPE BB248/U USED TO STAR--ETC(U)
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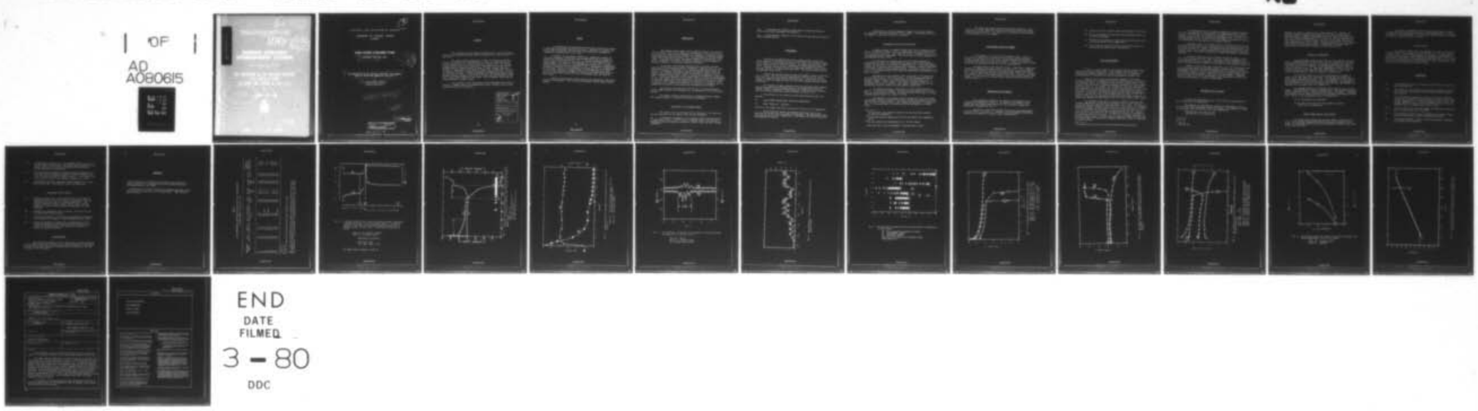

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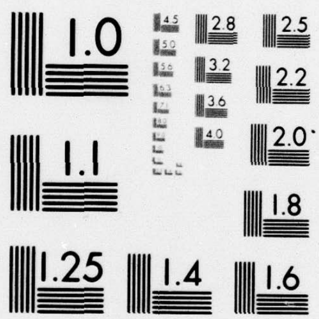

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL NOTE NO. 79-31

THE BEHAVIOUR OF THE MILITARY BATTERY TYPE BB248/U USED TO START THE ENGINE OF THE A.P.C.

by

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Energy Conversion Division

DREO-TN-79-31

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ABSTRACT

The performance of the lead-acid battery used to start the diesel engine in the Armoured Personnel Carrier (APC M113A1) was tested between -18° and -26°C.

The lowest ambient temperature at which a start can be achieved without the assistance of slave batteries is close to -20°C provided the initial temperature of the vehicle batteries is about -15°C. The average cranking current under these conditions is approximately 450A and 13Ah are expended during a cranking period of close to 2 min. Engine starting is difficult or impossible if the terminal voltage (TV) is below 16V. The use of auxiliary batteries, connected in parallel, increases the value of the TV and the start is easier. It was demonstrated that the charge passed through batteries during a charge period of 30 to 45 min. with the alternator -regulator system varies between 6.5 and 9.5Ah. This is markedly lower than the charge required to obtain a start.

The viscosity of the lubricating oil also influences the ability to achieve an engine start at low temperatures and two synthetic Arctic Grade lubricating oils were evaluated.

RÉSUMÉ

Le comportement des accumulateurs plomb-acide utilisés pour assurer le démarrage des véhicules militaires servant au transport du personnel des forces armées canadiennes (APC #M 113A1) a été étudié dans une gamme de températures comprises entre -18 et -26°C.

Le moteur, de type diesel, démarre à la température minimale de -20°C sans assistance d'accumulateurs auxiliaires alors que la température initiale des accumulateurs est de -15°C. Le courant de décharge moyen, la charge requise et la durée de cette décharge sont de 450A, 13Ah et 2 min, respectivement. Par ailleurs, les démarrages sont difficiles ou impossibles lorsque le voltage de sorti est inférieur à 16V. L'assistance d'accumulateurs auxiliaires se traduit par une élévation du voltage de sorti et le démarrage est plus aisé. De plus, la charge requise lors du démarrage varie entre 8.7 et 21.3 Ah tandis que la charge qui traverse les accumulateurs durant la marche du moteur oscille entre 6.5 et 9.5 Ah seulement pour une durée de 30 à 45 min.

Enfin, la viscosité de l'huile à moteur est susceptible d'influencer l'aptitude au démarrage. C'est ainsi que deux huiles "Arctic Grade" ont été testées.

INTRODUCTION

The Canadian Forces widely use the lead-acid battery for starting vehicle engines. One factor limiting the performance of this battery system is the very low Canadian winter temperatures, especially in Northern Regions, where temperatures are often below -20°C. The discharge and recharge capabilities of the lead-acid battery are markedly degraded at temperatures below -20°C. In addition, the energy and charge required to start an engine is generally expected to increase as temperature decreases.

In the past, the lead-acid batteries used in military vehicles were tested in the laboratory within a temperature range from +20°C to -40°C without any specific information on the conditions of discharge inside the vehicle. For example, the military battery type BB248/U used to start the engine of the Armoured Personnel Carrier (APC M113A1 was generally tested under a cranking current close to 300A to simulate the conditions in the field (1, 2). The overall objective of the present study is to test the performances of the diesel engine and the batteries used in the APC during several attempts to start the engine under severe temperature conditions i.e. close to -20°C. In addition, it is planned to established the influence of parameters such as temperature and nature of lubricating oils (Synthetic Arctic Grade).

It should be noted that the study is part of a Vehicle Mobility Section (DREO) project on the behaviour at low temperatures of the APC engine systems.

This paper is mainly involved with the behaviour during cranking and charging periods of the military batteries type BB248/U.

OBJECTIVES OF THE PRESENT REPORT

The present work is concerned with the behaviour of the batteries. The main objectives of the present report are the following:

(a) to determine the demands on the batteries during cranking periods at temperature close to -20°C in terms of cranking curent, the duration of cranking periods, the capacity required to obtain a start and other relevant parameters;

(b) to determine the conditions under which the batteries failed to obtain a start and investigate the reason(s);

(c) to determine the behaviour of the battery as used inside the vehicle during charging periods.

EXPERIMENTAL

Batteries type BB248/U were used as power sources to start the diesel engine of the Armoured Personnel Carrier (APC). Two batteries connected in series were used inside the vehicle. An insulated box having a small heater served to keep the initial temperature of these batteries close to -15°C. Sometimes, the assistance of two additional batteries (slave batteries) was required to obtain a successful start. The slave batteries were at a temperature close to 20°C.

The APC was situated inside the NRC cold chamber located in Building M-17 in Ottawa. The fuel tank was approximately 25% full with an Arctic Grade fuel prepared several months before the test. In each run, the first attempt to start the engine was done with the fully charged batteries inside the vehicle.

The terminal voltage, cranking current and internal battery temperature were recorded during cranking periods. The charge current and the imposed terminal voltage were recorded during the recharge of the batteries, with the alternator-regulator system previously set up at 27.5V.

The influence of two synthetic Arctic Grade Lubricating Oils was assessed:

(a) Conoco DN600 "POLAR START" (Synthetic Hydrocarbon)

(b) Emery "Frigid Go" (Diester).

Further in this report, they will be called oil "A" and oil "B" respectively.

The acid specific gravity was measured inside each cell of the batteries before and after each charge and discharge. The experimental conditions such as the oil used, temperature of the ambient air and the batteries are summarized in Table 1.

Simultaneously, relevant parameters related to the diesel engine are measured by the Vehicle Mobility Section (DREO). The vehicle was left in its chamber to soak for a day prior to testing.

EXPERIMENTAL RESULTS AND DISCUSSION

A general picture of terminal voltage (TV)* and the cranking current during a successful attempt to start a diesel engine in the Canadian Forces A.P.C. is given in Fig. 1**. The curves (a) and (b) correspond to the TV and the cranking current, respectively. The TV at rest of a fully charged set of batteries was 25.5V at -15°C.

On application of cranking load, the TV of 25.5V decreases to approximately 16V while the current peaks at about 625A*** (the breakaway current) and decreases to 515A within a second (Fig. 1). The TV then remains constant at 16V and the current progressively decreases as dynamic conditions in the diesel engine stablize during cranking. According to curve (b) in Fig. 1 & 2, the current equals 515A after one second and is approximately 450A after 30 seconds.

Cylinder assist (CA) periods, which correspond to the shaded areas at the bottom of Fig. 2, are also observed. As they become more frequent and their duration longer, the current required from the batteries is markedly reduced. It has a value of 420A after 90 seconds compared to approximately 10A after 120 seconds. This region - between (c) and (d) - is arbitrarily called the "active cylinder assists" region (ACA).

The cranking current is relatively low in the region between (d) and (e). In this typical example, the start occurred between 120s and 140s after the application of the load. According to curve (a) in Fig. 2, a lower cranking current results in a higher TV value.

Simultaneously, the imposed terminal voltage (TV) from the alternator-regulator circuit increases as the engine rotates and becomes high enough (22V) to force a charge current to flow through the batteries. According to Fig. 3*, the charge current is initially 112A and decreases to 24A after 2 min.

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*In this report, the terminal voltage of the two batteries connected in series is considered.

**The initial battery temperature was -15°C and vehicle bulk temperature -20°C.

***The pen response was approximately 0.5 s for full scale.

†Note that Fig. 3 is an enlargement of the last part of Fig. 1.

The charge that passed through the batteries during the 45 min. operation of the APC engine was calculated from the area under the current vs time curve given in Fig. 3 and found to be 9.5Ah which is less than the 12.9Ah required to start the engine.

INSTANTANEOUS VALUES OF CURRENT

An enlargement of the time scale from 20s/in (Fig. 1 and 2) to 1s/in (Fig. 4) shows cyclic current and TV variations during discharge. Without cylinder assist (CA) the cyclic current variations are within 4% of average value and only 2% for the TV (Fig. 4). Thus, the cranking current and TV may be considered constant in the first approximation.

Cylinder assists, also observed in Fig. 4, illustrate a significant decrease in cranking simultaneous with an increase in TV. In this example, the TV varried between 16 and 18.5V while the current dropped from 420A to 270A. The cylinder assist periods, reproduced in Fig. 2 for run 1, generally vary between 1 and 2s, and become larger in the active cylinder assist (ACA) region. In this latter area, large random cranking current variations are observed (Fig. 5).

REPRODUCIBILITY OF RESULTS

The experimental conditions and results corresponding to each experiment are summarized in Table 1. In addition, the cylinder assist periods and the cranking time required for the successful attempts are graphically represented in Fig. 6.

The runs 1, 2 and 3 were carried out under the same experimental conditions (Fig. 6 and Table I). Therefore, the corresponding experimental results may be compared to evaluate their reproducibility:

(a) time for the first cylinder assist was between 62.5 and 64.5s;

(b) the current demand from the battery was negligible after 115 to 117s of discharge;

(c) minimum initial terminal voltage* and peak current were 16.0V to 16.3V and 625A to 655A respectively;

(d) the voltage and current at 30s and the required capacity to obtain a start varied within a few percent.

USE SLAVE BATTERIES

In runs 4, 5 and 9 (Table 1) the internal vehicle batteries were used without any slave assistance. These attempts were unsuccessful. To determine the possible reason(s) of these no-starts, let us compare the characteristics of successful (SA) and the unsuccessful attempts (UA).

First of all, in case of unsuccessful attempts, the cylinder assistance periods occur comparatively late and their duration and frequency are relatively short. For example, during the 148s cranking period of the UA run #4 only one period of assistance having a duration of 1s was observed after 113s (Fig. 6). By contrast, the cylinder(s) fired many times before the completion of the SA attempt (run 4a) which had a duration of 112s. Note that in run 4a the slave batteries were used in conjunction with internal batteries. In addition, the cranking current and TV curves corresponding to UA (run 4) and SA (run 3 and 7) are slightly different (Fig. 7 & 8). It should be noted that the experimental conditions were similar except for the ambient air temperatures which were:(-18°C, #7)* (-20°C, #3)** (-22°C, #4)**.

The cranking current and the capacity required to obtain a start increase significantly as temperature decreases: for #7 (-18°C) 420A and 10.5Ah were observed compared to 458A and 13Ah for #3 (-20°C). As previously mentioned, a higher cranking current results in a lower TV (Fig. 8). Moreover the TV corresponding to the no-start (-22°C, #4) drops below 16V after 100s to be as low as 13V, 150s following the application of the load. The no-start may then be attributed to the relatively low value of TV delivered by the batteries during this interval. In this case, the power and energy required to obtain a start is greater than the power and energy available from the internal batteries under these cranking conditions. Hence, an unsuccessful start resulted.

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*the minimum TV value within one second following load application.

It was mentioned that a successful attempt was observed following run 4 with the addition of slave batteries at temperatures close to 20°C (run 4a). The (SA) and (UA) attempts are compared in Fig. 9 in terms of the cranking current and TV. The significant improvement in TV of about 2.4V (the improvement in power is 10%) for the SA attempt is attributed to the use of slave batteries in conjunction with internal batteries.

According to Fig. 9, the lowest value of the TV was 18V just before the active cylinder assists (ACA) region while the corresponding value of the UA attempt was only 16V. Again, this suggests that the no-start may be attributed to the low TV (or power) delivered by the vehicle batteries during the cranking period. The lowest TV required for start would appear to be greater than 16V.

It should be mentioned that SA attempt #4a exibited higher r.p.m.* (173) than UA attempt #5 (145). Thus, the r.p.m. tends to increase as the TV increases and the start is easier. Consequently, the cranking time and the capacity required decrease slightly with the help of slave batteries (Table 1).

Hitherto, the no-starts were attributed to the low TV value delivered by the batteries during the discharge periods. However, the very similar experimental conditions and results corresponding to UA attempt of run #5 and SA attempts of run #1, 2, and 3, especially the r.p.m. value, suggest that the batteries behaved similarly during each of these attempts. Therefore, failure to start in run #5 is attributed to some change which occured in an uncontrolled parameter(s), possibly condensation.

INFLUENCE OF OIL ON START

It should be remembered that oil "A" and "B" were used during runs #1 to #5 and #6 to #9 respectively.

The similarity of experimental conditions corresponding to runs #1, #2, #3 and #6 allows comparisons between the results. As summarized in Table 1, the current after 30s and the r.p.m. are respectively:

-425A and 159 r.p.m. with oil "B";
-450A and 142 r.p.m. with oil "A".

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* oil "B"

** oil "A"

† after 50-60s.

Therefore it should be easier to get a start with oil "B". However, the capacity required is significantly higher with oil "B" (run #6 and #8). This may be due to changes in properties of the fuel which could have occurred in the interval between runs 1 to 5 and 6 to 9. The fuel tank was less than 25% full and the vehicle warmed up to about +20°C during the weekend which separated the two sets of runs. During the second set of runs, condensation may have had an adverse effect. Consequently, the large capacity required may be tentatively attributed to this adverse effect.

INFLUENCE OF TEMPERATURE

From experimental values given in Table 1, the capacity is plotted against temperature (-18°C to -21°C) (Fig. 10). Note that oil "B" was used. The capacity increases markedly as the temperature decreases from 10Ah at -18°C to 21.4Ah at -21°C. However, it was impossible to obtain a start at -26°C with the use of oil "A". The lowest temperature at which a start was obtained without any slave assistance was -22°C (Table 1). The run #9, a no-start corresponding to -26°C, is discussed in detail below.

This run was carried out to collect information on attempts to start the APC under particular conditions. The APC was cold soaked from normal ambient temperature to about -40°C. The temperature of each component was recorded twelve hours later just prior to the attempt. The average of all temperatures was -24°C while the lowest value was -34°C (the ambient temperature) and the highest was -13°C (engine oil).

The terminal voltage, the discharge current and the r.p.m. at 30s (Table I) are high enough to expect an engine start. The continuous discharge period, longer than 3.5 min, illustrates good battery performance. Therefore the reason(s) for the failure to start are not related to the battery performance. However, they are suspected to be in relation with

(a) the low ambient air temperature

(b) the age of the arctic fuel and possibly an adverse effect due to condensation.

CHARGE PASSED THROUGH THE BATTERIES

The charge passed through the batteries during a charge period of 30 to 45 min with the alternator-regulator system varies between 6.5 and 9.5Ah. It is markedly lower than the charge required to obtain a start (runs #1 to #3 and #6 to #9).

In general, approximately 42% more charge than capacity required to start must pass through the batteries to fully recharge them. It should be remembered that measurements of acid specific gravity inside the batteries were used to evaluate the state of charge.

BATTERY WARM UP

As previously observed (2), the passage of a large current through a battery results in a warming of the battery (Fig. 11). In this example, the warm up may be detected approximately 30s following the application of the load and the internal battery temperature increases fairly linearly with time during the discharge. The temperature shifts from -16°C to -7°C. Note that the 30s cranking current was 420A (Table I). Thus, the warm-up of the batteries during discharge was relatively large.

CONCLUSIONS

(a) - the instantaneous value of cranking current drops as soon as one or more cylinders fire;

(b) - the duration of the cylinder assist periods is generally between 1 and 2s but they become longer and more frequent near the end of the discharge.

(c) - the lowest ambient temperature at which a start can be achieved without the assistance of slave batteries is close to -20°C if the initial temperature of the vehicle batteries is about -15°C. The average cranking current is then approximately 450A, and 13Ah are expanded during a cranking period close to 2 min.

(d) - the use of warm slave batteries extends the temperature range over which an engine start can be attained;

(e) - the assistance of slave batteries increases the terminal voltage value and consequently to power available during start;

(f) - the capacity required to obtain a start may increase considerably as the temperature decreases.

(g) - considering the value of r.p.m. and cranking current, the use of oil "B" should be beneficial. The larger capacity required to get a start with the use of "B" may tentatively be attributed to adverse effect(s) of condensation;

(h) - the charge passed through the batteries during a charge period of 30-45 min with the alternator-regulator system is markedly lower than the capacity required to obtain a start. It is partially due to the very low value of the regularor voltage, i.e. 27.5V;

(i) - approximately 42% more charge than capacity required for a start must pass through the batteries to fully recharge them.

SUGGESTIONS FOR THE FUTURE

(a) - perform a similar study of the batteries over a wide range of temperatures from 0°C to -30°C keeping the initial battery temperature inside the vehicle at the bulk temperature. The capacity required to obtain a start and the r.p.m. should be compared for starts with and without the assistance of slave batteries;

(b) - determine the temperature limit to obtain a start with the use of internal and slave batteries;

(c) - control the composition of fuel during experiments and determine the influence of the amount of fuel contained inside the tank;

(d) - during the charging of batteries at low temperature with the alternator-regulator system, measure the acid specific gravity versus time to determine the time required to partially or entirely recharge the battery.

ACKNOWLEDGEMENT

The authors are indebted to Mr. G. Hutton and G. Webster (formerly with the DREO Vehicle Mobility Section) who kindly invited us to participate in their project which was mainly concerned with the behaviour at low temperatures of the APC engine.

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2. L. Brossard and L.D. Gallop, "Evaluation of BB248/U Lead-Acid Battery During Charge-Discharge Cycle at Low Temperature". DREO Technical Note No. 79-15.

<u>TABLE 1</u>

THE EXPERIMENTAL CONDITIONS AND THE RESULTS OF CORRESPONDING TO EACH ATTEMPT OF RUNS #1 to #9

Experiment Number	Bulk Temp. (°C)	Battery Temp. (°C)	End of Significant Demand in Current (s)	Peak current (A)	Voltage after 30s (V)	Current after 30s (A)	R.P.M. 50-60s	Capacity Required to start (Ah)
1*	-20	-15	120	625	16. 4	450	136	12.9
2*	-20	-15	117	642	16.25	450	146	13.2
3*	-20	-15	117	655	17. 3	458	146	13.0
4*	-22	-15	No-start	697	17. 2	472	138	
4A*	-22	(1)	115	600	19. 2	455	173	12.6
5*	-20	-16.5	No-start	677	17. 2	460	145	
5A*	-20	(1)	94	562		430	183	8.7
6**	-20	-16	178	598	17. 5	425	159	18.9
7**	-18	-15	96	580	18. 2	420	170	10.2
8**	-21	-15.5	197	610	17. 8	430	158	21.3
9**	-26	(1)	No-start	655	18. 4	430	168	----

*:011 "A"

**:011 "B"

(1):A.P.C. batteries at bulk temp +two slave batteries at +20°C

The r.p.m. was calculated from the current transients as illustrated in Fig. 4. The peaks were counted for an interval of 10s and averaged for 1s. This number was divided by 3 - 3 per revolution - and multiplied by 60 to convert to r.p.m.

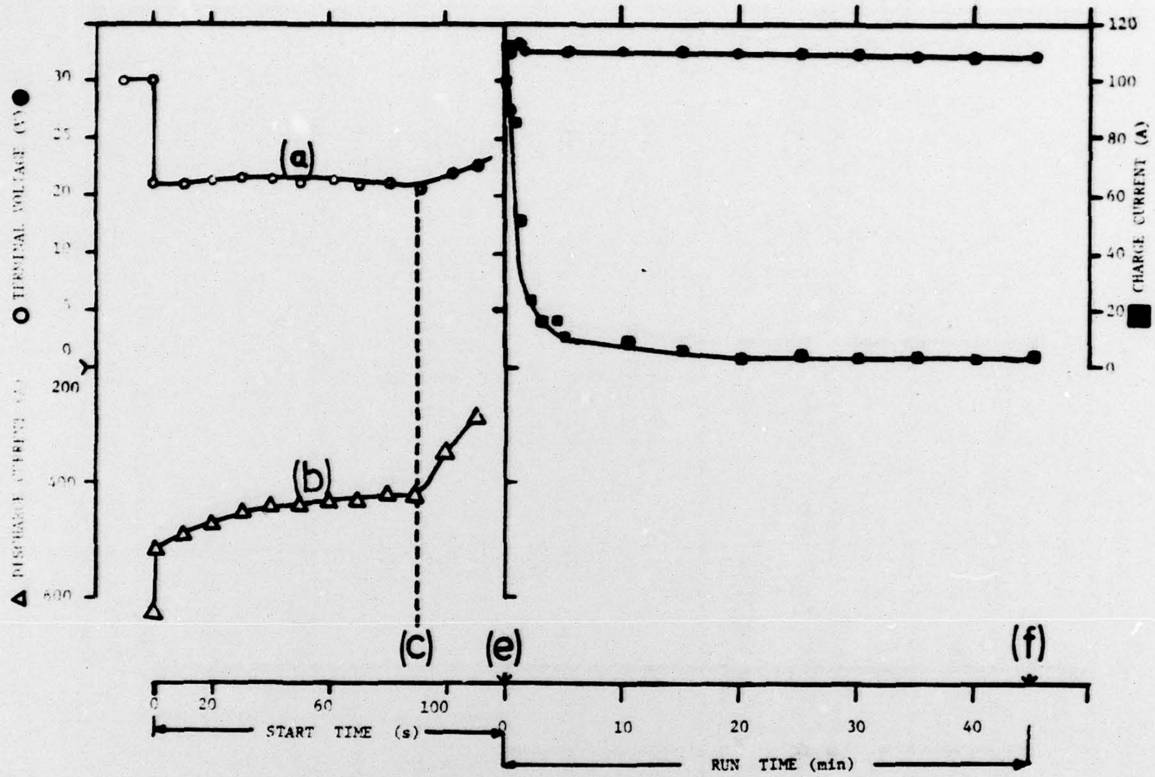

Fig. 1. A typical example of the TV and the cranking current value during a successful attempt to start the diesel engine. The imposed terminal voltage from the alternator-regulator system and the charging current are also given. These results correspond to run #1.

Curve (a): TV (terminal voltage)
Curve (b): discharge current

Experimental conditions

Bulk Temp.:-20°C
Init. Batt. Temp.: -15°C

The charge region: between (e) and (f).

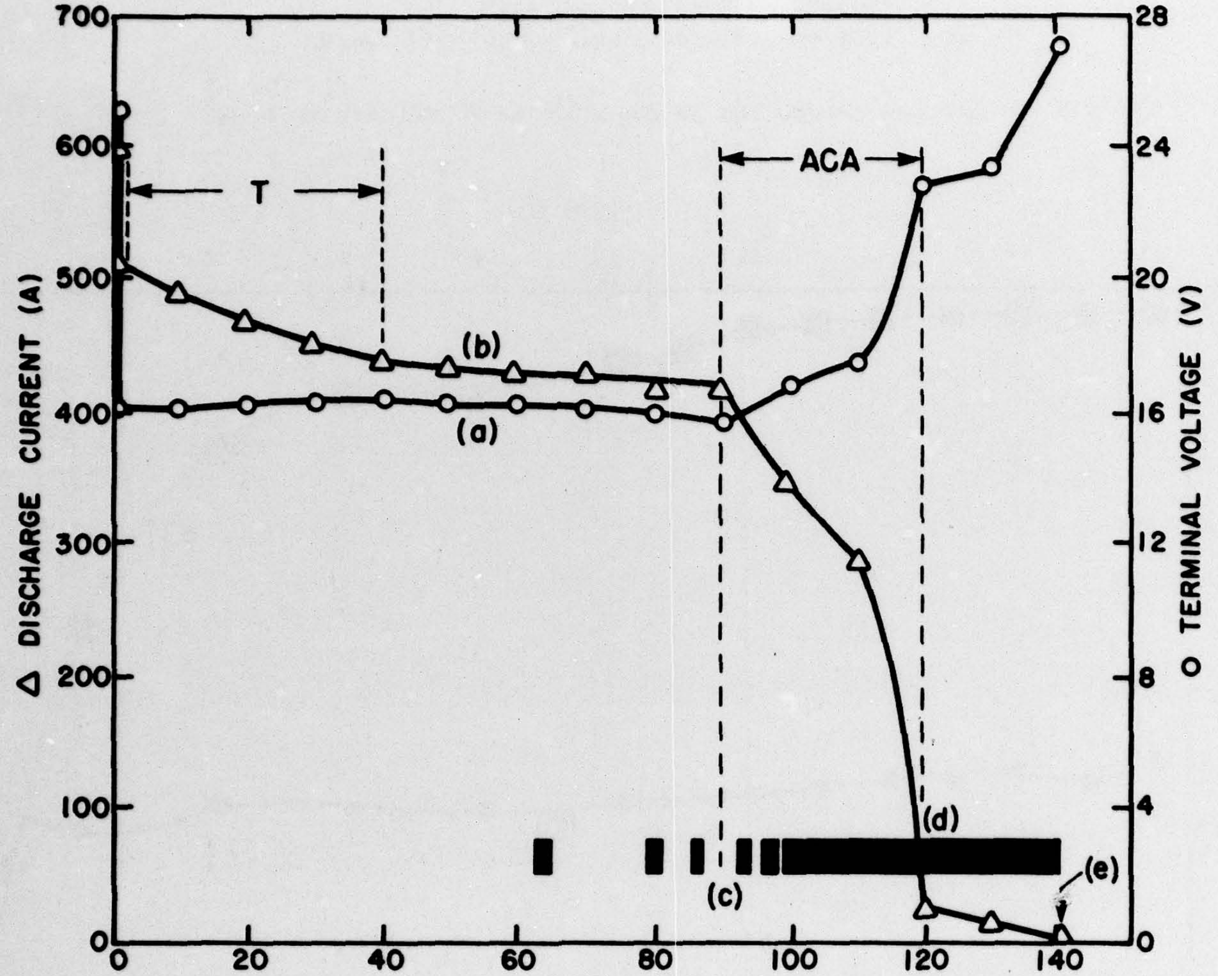

Fig. 2. *These curves are an enlargement of the cranking curves reproduced in Fig.1. The periods of cylinder assist (CPA) are also shown in shaded areas.*

Curve (a): TV
Curve (b): cranking current
T: transition region
ACA: the cylinder assists region

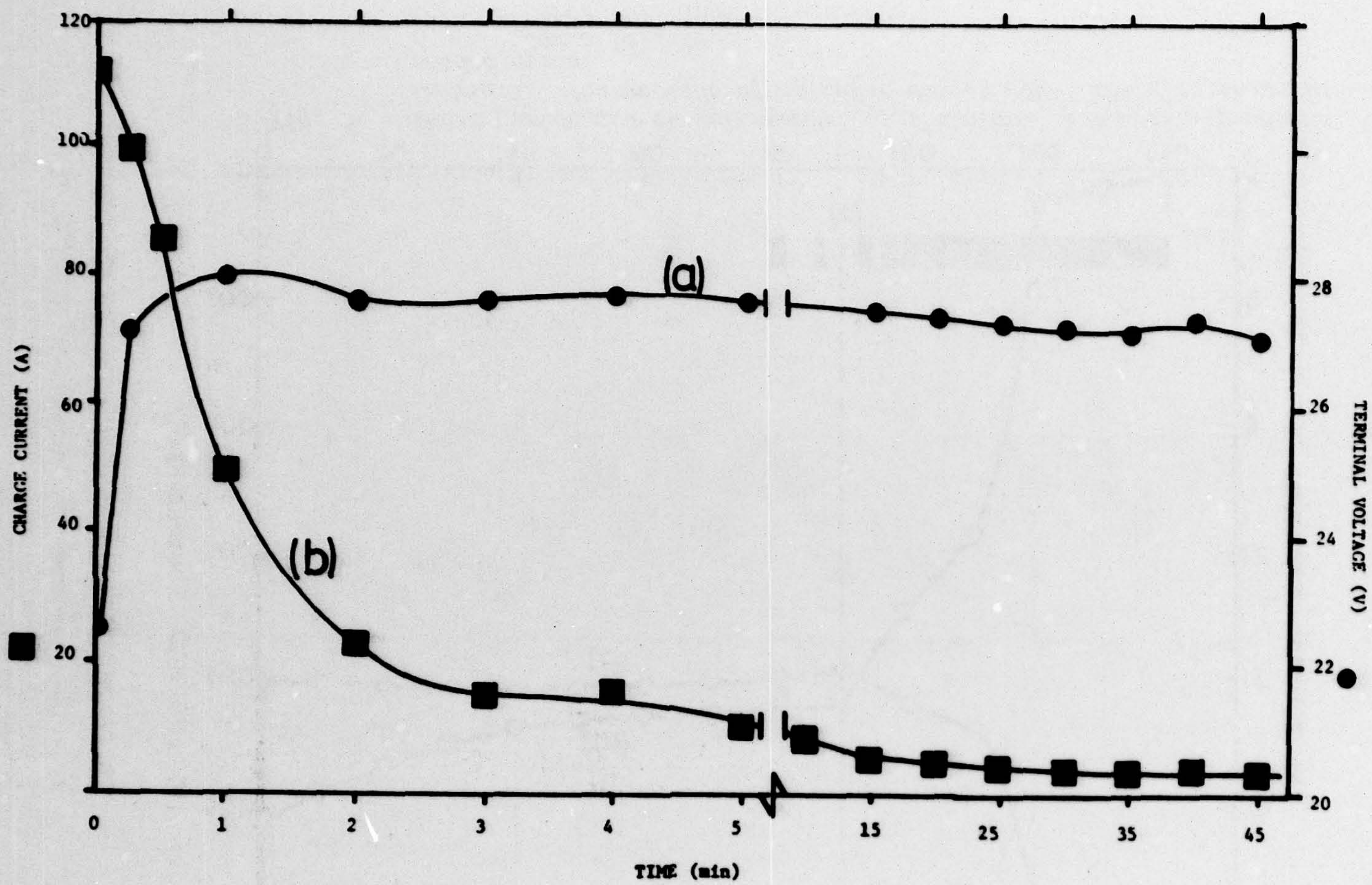

Fig. 3: *These curves are an enlargement of the curves between (e) and (f) in Fig. 1.*

Curve (a): the imposed terminal voltage from the alternator-regulator system.

Curve (b): the charge current.

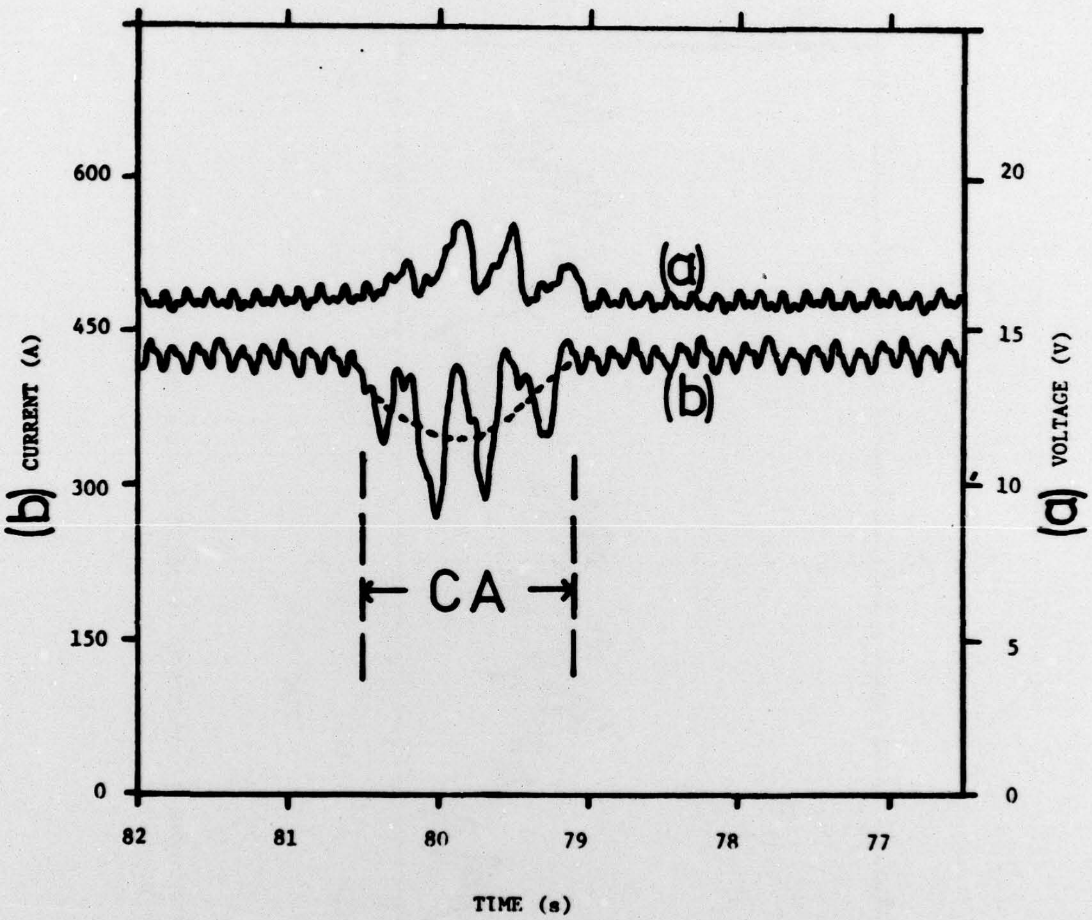

Fig. 4. The variations of current and TV between 77s and 82s following the application of the load (Fig.2).

Curve (a): the TV
Curve (b): cranking current
CA: Cylinger assist period

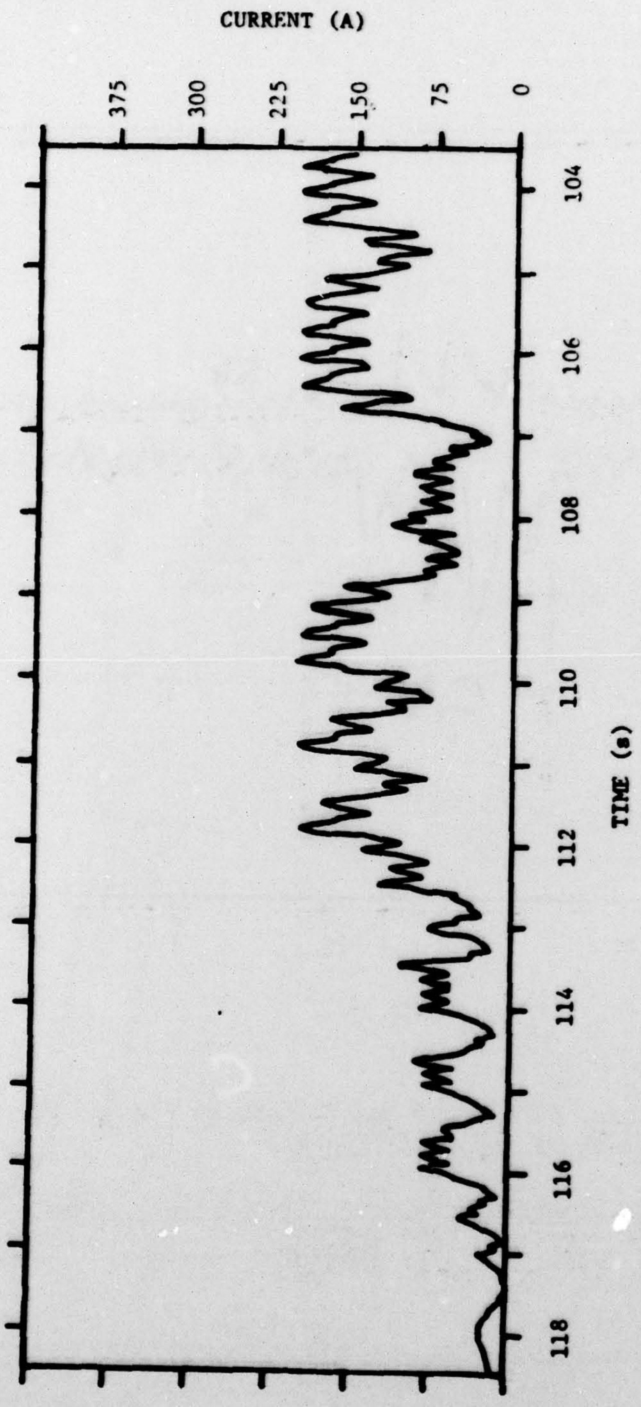

Fig. 5: The variations of cranking current in the active cylinder assists region.

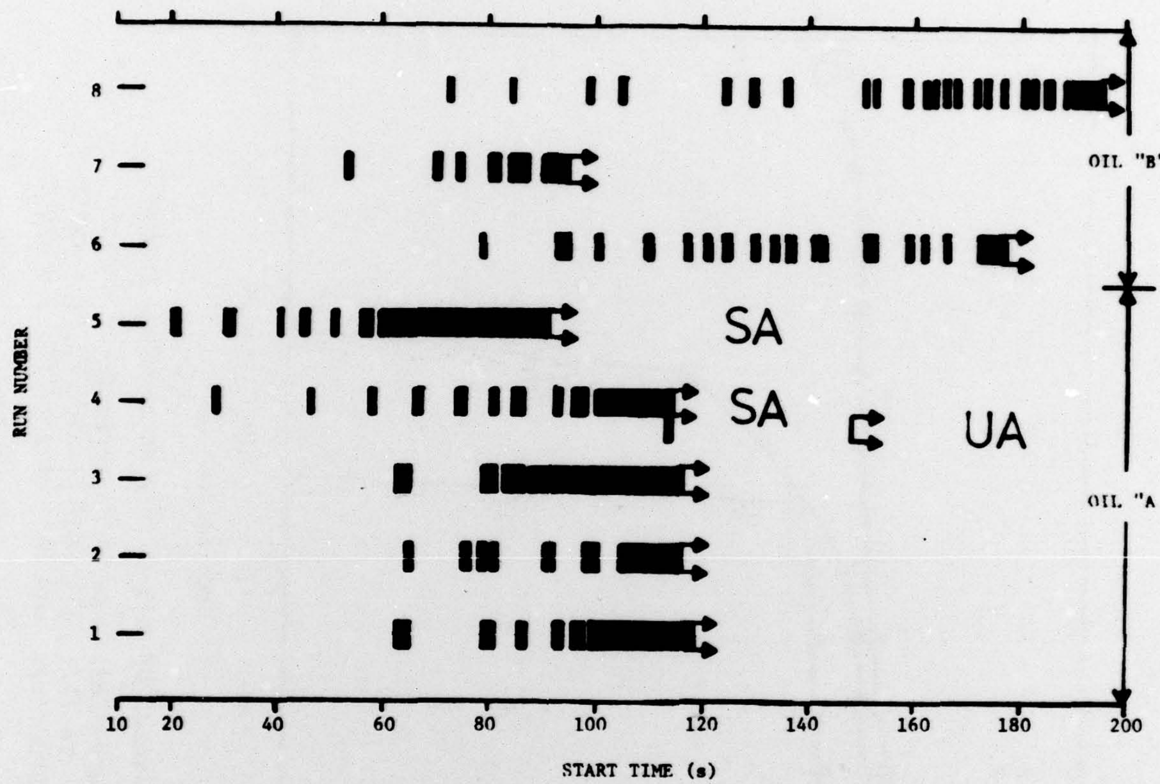

Fig. 6: The period of cylinders assists and their duration corresponding to each attempt.

: End of significant demand in current
UA: UNSUCCESSFUL ATTEMPT
SA: SUCCESSFUL ATTEMPT
Note that all attempts are successful except those marked UA.

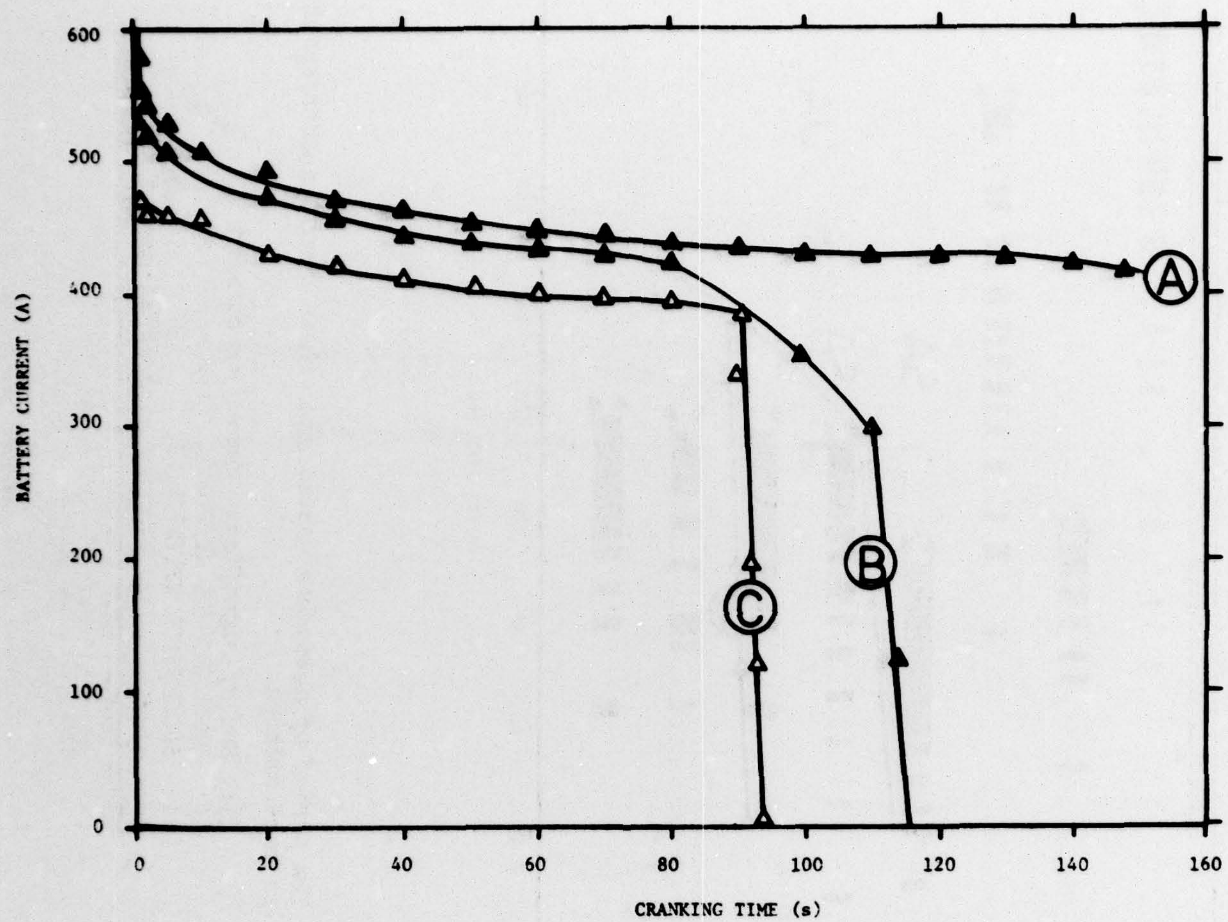

Fig. 7: The influence of temperature on cranking current.

Curve (a): the UA attempt #4, T = -22°C*
*Curve (b): the SA** attempt #3, T = -20°C*
*Curve (c): the SA** attempt #7, T = -18°C*

** UA - unsuccessful attempt*
*** SA - successful attempt*

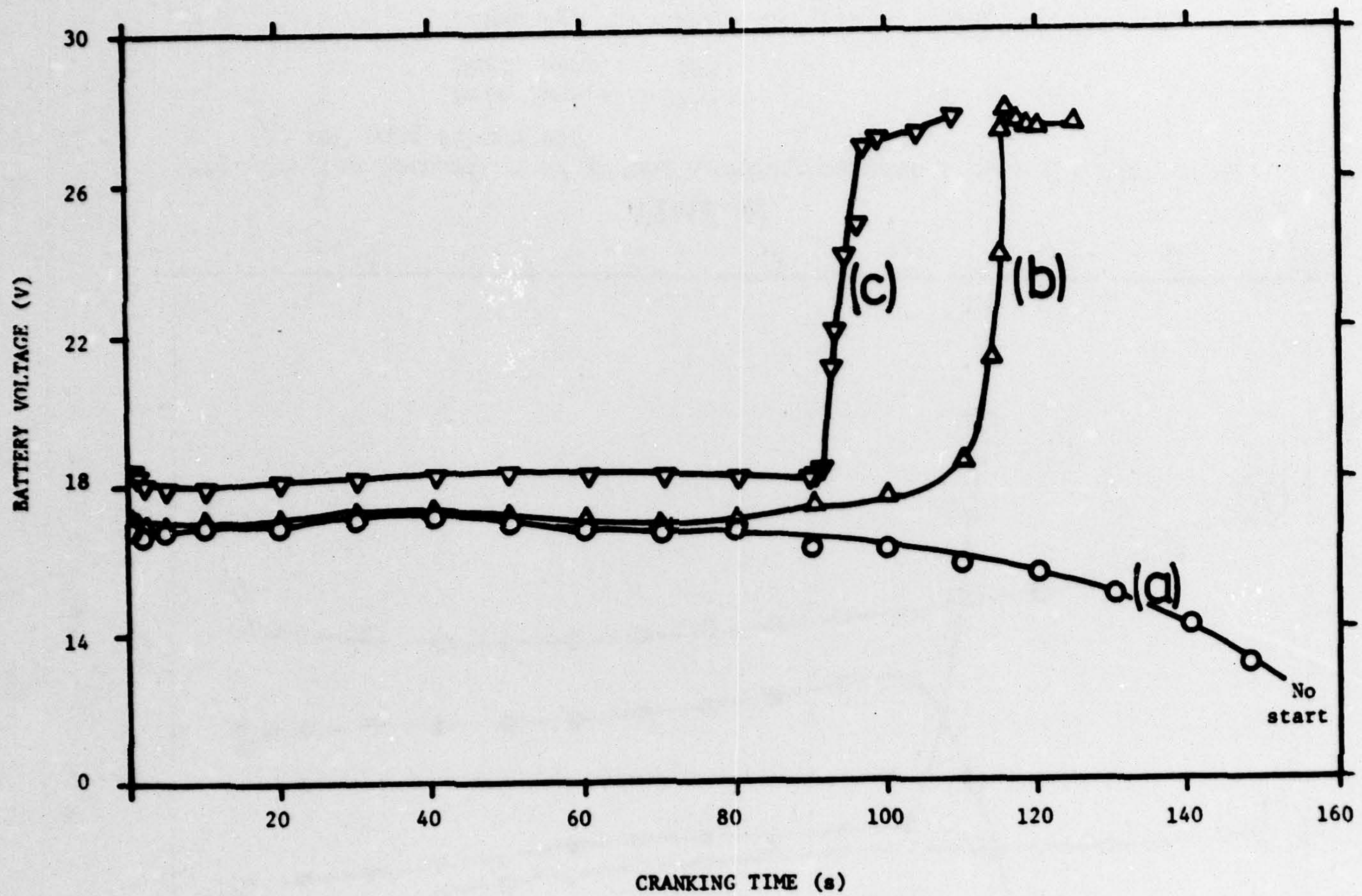

Fig. 8: The influence of the temperature on terminal voltage during a discharge. The experimental conditions are given in caption of Fig. 7.

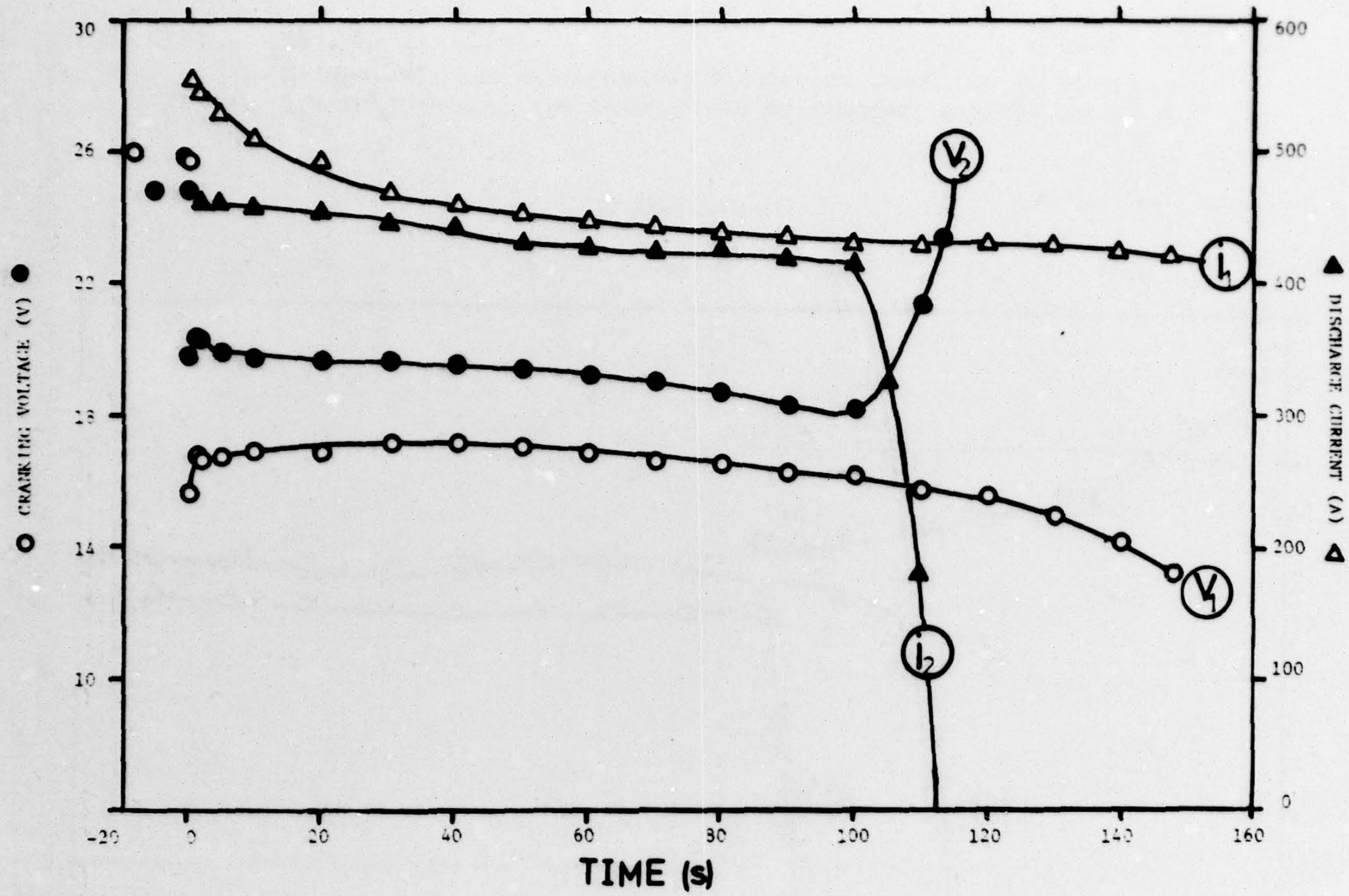

Fig. 9: The comparison of TV and cranking current during the USA and SA of runs #4 and #4a.

Bulk Temp.: -22°C
Batt. Temp.: -15°C

Curve V_2: TV during SA attempt (slave assistance)
Curve V_2: TV during UA attempt (without slave)
Curve I_2: Cranking current during SA attempt
Curve I_1: Cranking current during UA attempt

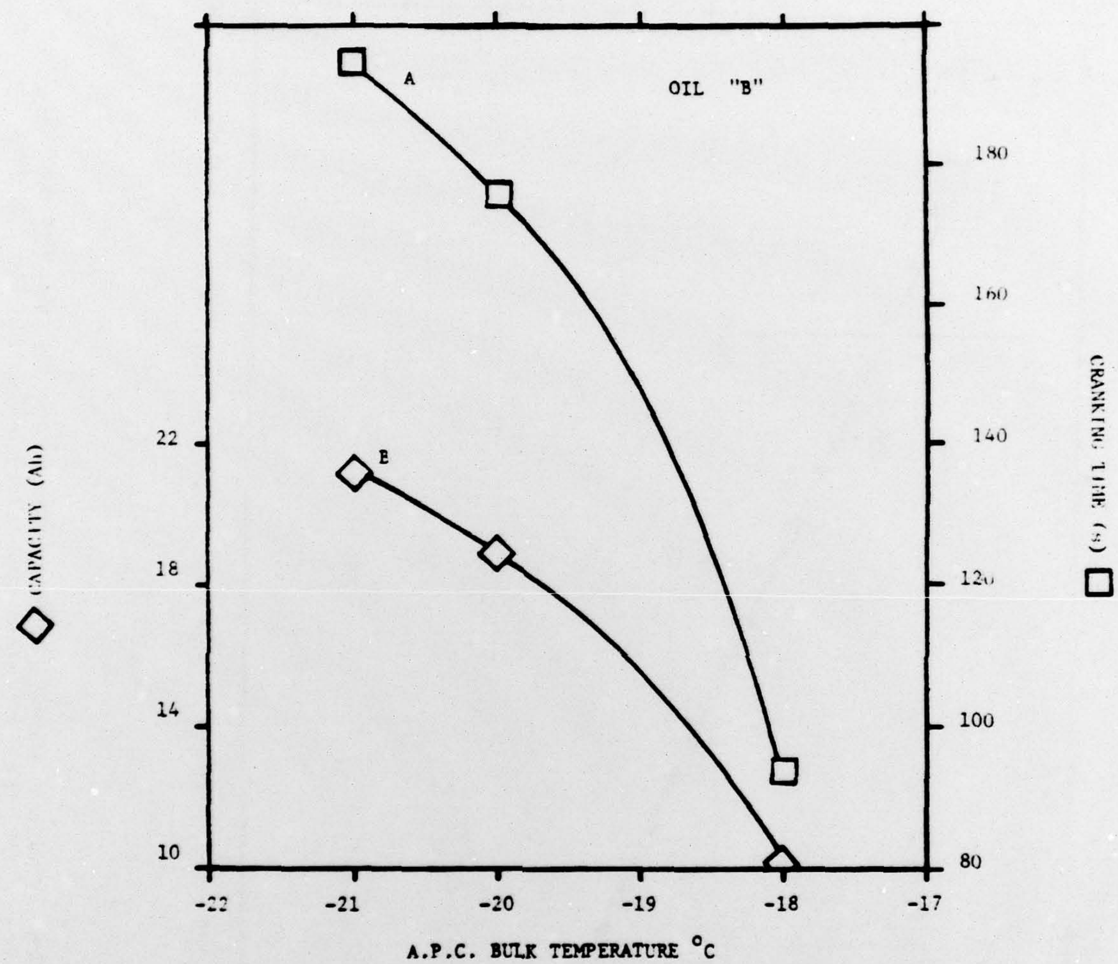

Fig. 10: The capacity required to obtain a start and the cranking time versus temperature. The oil "B" is used.

Curve (a): Cranking period
Curve (b): Capacity

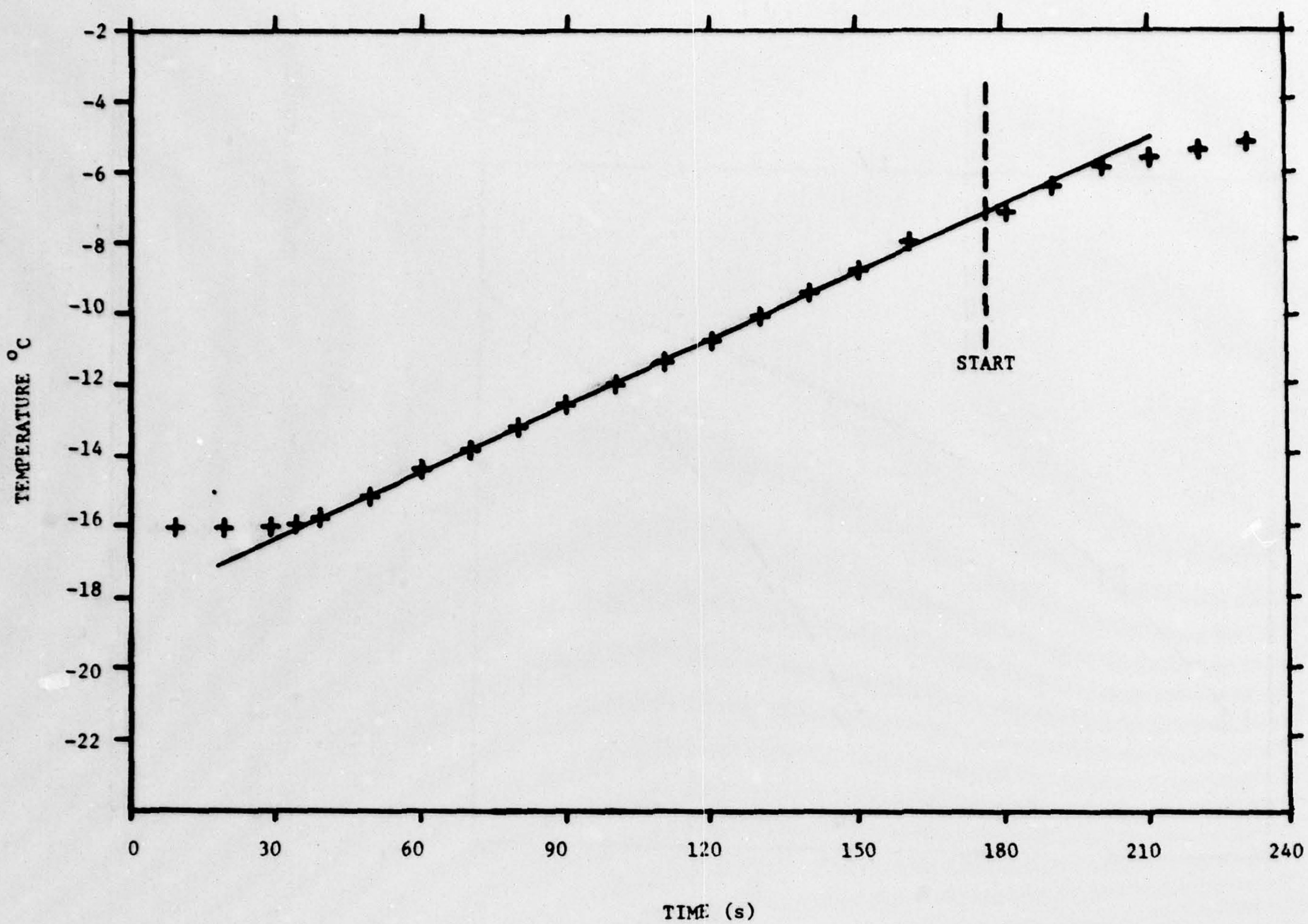

*Fig. 11. The internal battery temperature versus time **during** cranking period of start #6. The average cranking current is 425A.*

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13. ABSTRACT

The performance of the lead-acid battery used to start the diesel engine in the Armoured Personnel Carrier was tested between -18° and -26°C.

The lowest ambient temperature at which a start can be achieved without the assistance of slave batteries is close to -20°C provided the initial temperature of the vehicle batteries is about -15°C. The average cranking current under these conditions is approximately 450A and 13Ah are expended during a cranking period of close to 2 min. Engine starting is difficult or impossible if the terminal voltage (TV) is below 16V. The use of auxiliary batteries, connected in parallel, increases the value of the TV and start is easier. It was demonstrated that the charge passed through batteries during a charge period of 30 to 45 min. with the alternator-regulator system varies between 6.5 and 9.5Ah. This is markedly lower than the charge required to obtain a start.

The viscosity of the lubricating oil also influences the ability to achieve an engine start at low temperatures and two synthetic Arctic Grade lubricating oils were evaluated.

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Security Classification

KEY WORDS

LEAD ACID BATTERIES

LOW TEMPERATURE

VEHICLE STARTS

DIESEL ENGINES

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