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BENCHMARKED COMPARISON OF THE TSS/360, CP/67, MTS and OS/MVT COMPUTER OPERATING SYSTEMS

by

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ABSTRACT:

A set of terminal scripts and benchmarks have been derived for comparing the performance of time sharing and batch computer operating systems. Some of the problems encountered in designing valid benchmarks for comparing computer operating systems under both terminal and batch loads are discussed.

The results of comparing TSS/360, CP/67 and MTS time sharing systems for the IBM 360/67 over a wide range of load conditions are presented. The results of comparing TSS, MTS and OS/MVT under batch loads are also presented.

Serious performance degradation of the time sharing computer systems from overloading was experienced and a simple solution is suggested to prevent such degradation. The degradation was so severe as to render the performance less than that of a sequential job processor system.

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Section 1

INTRODUCTION AND SUMMARY

1.1 Introduction

With the increased economic pressure on most computer centers, there is an increased need for accurate comparison of different computer systems and different operating systems on a particular computer system. The problem of selecting an operating system for a large computer system is a "difficult" task, especially when there are several available operating systems. The selection is difficult because the techniques for comparing computer performance are not well developed (especially for time sharing systems), the number of variable system parameters is almost unlimited, and the operating systems have significant effect on the performance of the computer system. In fact, selecting a better operating system may even double the performance of a four million dollar computer system.

Although monitoring the computer performance under actual operating conditions is the most accurate, it is difficult to make comparisons or measure improvements in performance under these conditions. Thus there is a need for loading the computer in such a way that it is repeatable from day to day and from one operating system to another. Although the technique of using a fixed benchmark or set of programs has been used on numerous occasions to measure the performance of batch operating systems, an equivalent technique apparently has not been widely used to measure time sharing systems.

Although the problem of optimizing the performance of time sharing systems is much more difficult than for its batch counterpart, it is felt that the benchmarking technique is also useful for time sharing systems. In a batch operating system, there are relatively few user programs competing for system resources at any one time. Thus, it is relatively simple to collect a set of benchmark programs that are representative of a "typical" load and that could be used for evaluating and comparing the computer systems. On the other hand, in a time-sharing system there are many user programs competing for resources and, at any one time, there may be many requests for a particular resource. Since there are so many combinations of requests, it is very difficult to construct a set of test programs (or scripts) that will represent a "realistic" load for comparing several time-sharing systems. Also, the time-sharing monitors (schedulers) handle the requests differently and, as a result, the same scripts present very different loads on the different systems thereby producing large differences in performance. Thus the first objective of this project was to develop a set of terminal test programs or scripts suitable for loading and comparing the performance of time sharing systems. These scripts were then to be used to compare the performance of four operating systems for the IBM 360/67 computer under a wide variety of loading conditions.

1.2 Operating Systems

The four major operating systems for the IBM 360/67 computer and the ones that were compared are:

(1) IBM's TSS/360 - Time Sharing System, version 7 with schedule table T49 [1]*,

*Reference 1

(2) IBM's CP/67 - Control Program/1967 developed by the Cambridge Research Center in Cambridge, Mass., version 3.0,

(3) MTS - Michigan Terminal System developed by University of Michigan, versions 2.0 and 2.1, and

(4) IBM's OS/MVT - Operating System/Multiprogramming with a Variable number of Tasks, Release 15/16.

In this report, these operating systems will be referred to as simply TSS, CP, MTS and OS respectively.

Three of the operating systems, TSS, CP and MTS, were designed primarily as time sharing (or terminal) systems, but TSS and MTS also have batch handling capabilities. On the other hand, OS was designed primarily as a batch operating system , although small time sharing operating systems are sometimes run under OS as one of the tasks*. Another major distinction in these systems is that TSS and MTS can operate with one or two processors (CPU), while CP and OS can operate with only a single processor.

Since both batch and terminal services are required at this installation, the system (or systems) chosen must support both requirements. For most of the time, the IBM 360/67 computer has been run as a split system with CP providing the terminal services and OS providing the batch services. For a brief four month period from September to February 1971, TSS provided both the batch and terminal services.

*Time sharing operating systems that run under OS/MVT-such as CALL/360-OS, CPS (Conversational Programming System), ITF (Interactive Terminal Facilities) ATS (Administrative Terminal Services), APL/360 and the new TSO (Time Sharing Option of OS) offer only restrictive capabilities and generally poorer performance than the general time sharing systems and therefore are not considered here.

The second objective, and the reason for the initiation of this project in January 1971, was to compare the performance of CP with that of TSS. The third objective was to compare the total performance of the split system (CP and OS) with that of TSS. The fourth objective was to compare the performance of the split system with that of the Michigan Terminal System, MTS. The performance was to be compared by placing a terminal load on CP and a batch load on OS, and then placing the same combined terminal and batch load on MTS, and measuring the resultant performances in all cases.

The fifth and final objective was to supply management with information that will assist in their decision of whether to continue running the split system (CP and OS) or to adopt MTS as the one operating system to handle both the terminal and the batch computing requirements.

The next sections will describe the NPS computer configuration and the configurations that were tested in order to satisfy the above objectives.

1.3 Computer Configuration at NPS

The IBM 360/67 at NPS has the following configuration (Figure 1):

Two	2067	central processor units (CPUs),
Three	2365	core boxes (768K bytes),
One	2314	direct access storage unit (8 disk drives),
Eight	2311	disk drives (1/2 the speed of 2314), and
One	2301	drum storage unit.

For TSS and MTS the tests were conducted using the full configuration.

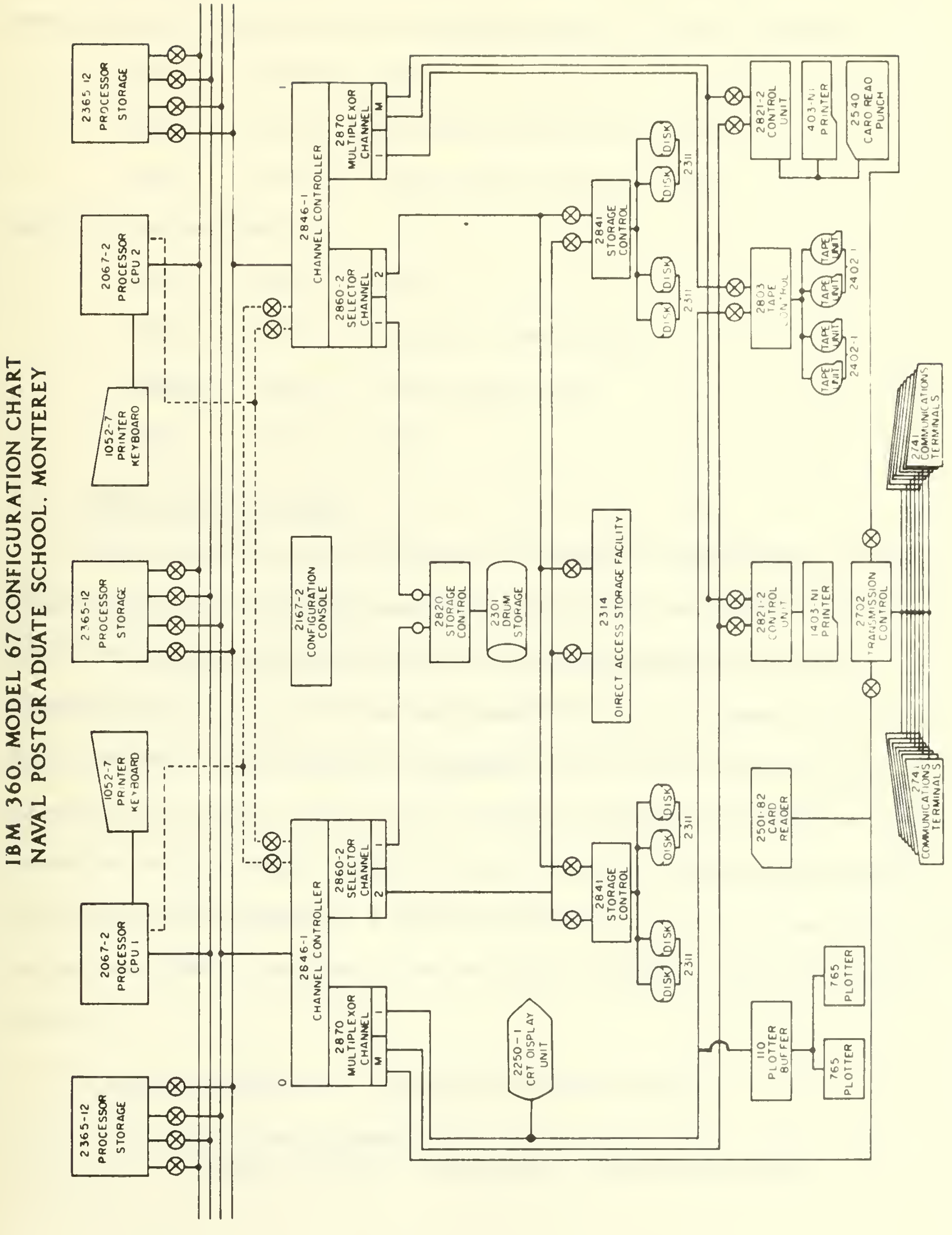


Figure 1 NPS Computer Configuration

On the other hand, when the system was run as a split system, the resources were divided in the following manner. OS was assigned:

One	2067	CPU,
Two	2365	core boxes (512K bytes), and
One	2314	direct access storage unit;

while CP was assigned:

One	2067	CPU,
One	2365	core box (256K bytes),
Eight	2311	disk drives, and
One	2301	drum.

1.4 Configurations Tested

Since one of the objectives was to compare the performance of TSS with CP under the configurations used at NPS, the tests were conducted with both systems configured as above, thereby giving CP a serious disadvantage. In fact, CP had only one-third the core memory, the slower disks and only one processor as compared to the full system for TSS. This comparison was made to show that if CP could compete with TSS under these conditions with terminal load only, then it would be much more economical to run this installation as a split system rather than as a dual processor system under TSS. Essentially the OS batch thoughput would be obtained for free.

Thus the following six configurations were tested:

(1) TSS - Full System
(Dual processor, 768K memory, 2314 disks, drum)

(2) CP - Single Processor, 256K Memory, 2311 Disks, Drum

(3) CP - as above but with 512K Memory

(4) OS - Single Processor, 512K Memory, 2314 Disks, No Drum

(5) OS - Full system except for single processor

(6) MTS - Full System

1.5 Summary of Objectives

Thus the objectives of this project are summarized as follows:

(1) To develop a set of terminal scripts suitable for loading and benchmarking the performance of different time sharing operating systems.

(2) To compare the performance of CP with that of TSS under the configurations at NPS (One core box, single processor and slower disks for CP; three core boxes, dual processor and faster disks for TSS).

(3) To compare the performance of the split system (CP and OS) with that of TSS with a full configuration.

(4) To compare the performance of the split system with that of MTS - the Michigan Terminal System.

(5) To supply information for management to assist in making the decision of whether to stay with the split system or to adopt a single operating system like MTS for both batch and terminal services.

1.6 Summary of Results

Before describing the details of the tests performed and the performance measured, a summary of the results are presented in this section. The major results are:

(1) A basic set of six scripts was developed for loading and comparing performance of different time sharing operating system. (Other scripts were also developed for use in other conditions such as sampling the normal operating load.)

(2) CP with a single core box (256K bytes), one processor and slower disks out-performed TSS with three core box (768K bytes), two processors and faster disks over almost all tested loading conditions.

(3) Operating the split system with CP and OS provided much better performance than running the full system under TSS, because the batch service from OS was obtained for essentially free. See result 2 above.

(4) MTS with a full system out-performed CP running with a limited system of one or two core boxes by a wide margin. In fact, the performance from MTS with two processors and three core boxes was more than three times that of CP with one core box and a single processor.*

(5) CP with two core boxes (512K bytes) had almost double the performance of CP with only one core box (256K bytes).

(6) From results 4 and 5 above, it was concluded that MTS would outperform CP even if both systems were given the same amount of core memory and thus essentially same resources. (There was not sufficient justification to do these tests.)

(7) TSS out-performed OS on batch-only jobs by a small margin.

(8) MTS out-performed OS on batch-only jobs by a wide margin.

*The single processor restriction is a limitation of CP, not the tests performed.

Although the tests comparing CP and MTS under terminal load only and the tests comparing OS and MTS under batch load only have been completed and are reported here, the final MTS tests in which the load includes the terminal load from CP plus the batch load from OS have not yet been completed. The final testing of MTS is currently awaiting the arrival of latest distribution of MTS, namely Distribution 3.0. Thus, it is not yet possible to make a definite recommendation to management on whether to retain the split system or to adopt MTS, although there is significant evidence in favor of MTS.

The purpose of writing this report at this time is to consolidate the results from the tests already performed, and to provide motivation for completing the comparison of the performance of the split system to that of MTS. Previously reported work from which this report has drawn included Haines' and Porterfield's thesis [2] and Hinson's thesis [3]. In both cases extensive analysis and several comparisons are made beyond that reported previously.

Section 2

METHODS OF APPLYING LOADS AND MEASURING PERFORMANCE

Before discussing the actual tests performed and presenting the results, this section will discuss some of the possible methods of applying loads and methods of measuring performance of computer systems.

Even after deciding on a computer configuration, there are many choices of techniques for empirically comparing operating systems. The following selections must be made: first, the method of applying the load; second, the method of measuring performance; third, the actual test loads to be used within the selected methodology; and fourth, the actual data to be collected within the performance measurement methology.

2.1 Possible Methods of Applying Loads

There are seven basic methods of applying loads to batch and terminal oriented computer systems. These are:

(a) Normal User Load: the normal user load is applied under actual operating conditions. This is the most realistic load but is the most difficult to duplicate and therefore unsatisfactory for comparing performance of different operating systems.

(b) Batch Benchmark: a set of programs are selected as "typical" jobs and run as a jobstream. This method is commonly used for measuring batch oriented computer systems.

(c) Terminal Benchmark: a set of "typical" programs are selected as in the batch benchmark case, a set of terminal scripts are written to call these test programs in a predetermined order, and finally, the number of each script to be run for each benchmark is selected.

(d) Terminal Probe: A terminal script containing several "typical" programs is used to probe the response under normal operating conditions. This is a combination of methods (a) and (c) above.

(e) Indirect Synthetic Job: A program is written, normally in a high level language, that has parameters to control the memory, processor (CPU) and input/output requirements. The same program with different parameters representing different resource requirements is run on several terminals. An example of such a job is a Fortran matrix multiplication program that changes (possibly in some random fashion) its memory, CPU and I/O requirements.

(f) Direct Synthetic Job: a program is written, normally in assembler, that directly controls the memory, CPU, I/O and supervisor requirements. As in case (e) above, the same program with different parameters is run on several terminals. An example of such a job is A JOB written at the Naval Postgraduate School [4].

(g) Direct load by another Computer: A mini-computer is used to generate the memory, CPU, I/O and supervisor requirements for the computer under evaluation. MITRE has developed such a Remote Terminal Emulator [5].

The criteria for selecting a loading method include repeatability, realism (accuracy in representing the real load), interference with normal operations, development effort, ease of performing the tests, and transferability to other systems. Table 1 shows the rating of each loading method against each criteria. Two comments concerning Table 1 are: (1) that the realism depends greatly on how consistent the normal user load is and how well it has been measured; and, (2) high interference means that a dedicated system is required to perform the test, such as in the benchmarking case.

A little simple arithmetic shows that there were a very large number of possible test conditions, even after all the above selections have been made. For example, since there were six operating systems configurations to be tested and seven types of loading, there were a total of 42 possible tests for each point on the load curve (independent variable). The next section will discuss how the number of possible test conditions was restricted.

2.2 Actual Loads Used

Four of the seven possible methods of loading a computer system were used in this project. A batch benchmark was used to compare TSS, OS and MTS under batch operation. A terminal benchmark was used to apply a terminal load for comparing TSS, CP and MTS under time sharing operation. A terminal probe was used to verify that ranges of loading used in the tests were realistic. (The probe was also used to isolate users who were overloading the system.) An indirect synthetic job was used to compare performance of CP and MTS at NPS (and at the University of Alberta in Edmonton, Alberta, Canada [6]).

	CRITERIA FOR COMPARISON						
Loading Method	Applicability (batch or terminal)	Repeatability	Realism	Interference	Development effort	Ease of performing test	Transferability between systems
Normal user load	batch or terminal	very poor	the best	N.A.*	N.A.*	N.A.*	None
Benchmark	batch	good	medium	high	low	easy	good
Script	terminal	medium to good	fair to medium	high	medium	difficult	fair to medium
Probe	terminal	good	very good	minimal (5%)	medium	very easy	fair to good
Indirect Synthetic Job	batch or terminal	medium to good	medium	high**	low to medium	difficult**	good
Direct Synthetic Job	batch or terminal	very good	good	high**	medium to high	difficult**	fair
Direct load by mini-computer	terminal	very good	good	high	very high	medium	poor

*N.A. - Not applicable

**Could also operate synthetic jobs as probes rather than the assumed benchmarks.

Table 1: <u>Comparison of Loading Methods</u>

A fifth method of loading - the Direct Synthetic Job - has not been used in the evaluation tests although it was developed at NPS [4]. The sixth method - normal user load - was not used for the tests because of its poor repeatability from day to day and its poor transferability from system to system.

Since the number of configurations and loading methods was so large, it was decided to limit the type of loading on each configuration: batch and terminal benchmarks for TSS; terminal benchmarks, terminal probes and indirect synthetic jobs for CP single core-box system; terminal benchmarks for CP dual core-box system; batch benchmarks for the two OS configurations; and batch and terminal benchmarks for MTS. This still meant that nine different loading and configuration combinations were tested in this project. Even this number was too large for evaluating over a reasonable range of loads and thus the number of test loads had to be restricted on certain configurations. Even so, a total of about 60 test runs were made.

2.2.1 Terminal Benchmarks

Although the development of the terminal benchmarks was really an outgrowth of the batch benchmark concept, the terminal benchmarks are described first to be consistent with the later ordering of the performed tests. Actually this script loading approach was first suggested by Karush as the stimulus approach for benchmarking the ADEPT-50 time sharing system at Systems Development Corporation [7]. Since a standard set of terminal benchmarks apparently does not exist for comparing time sharing systems, a set of terminal scripts was developed and used as terminal benchmarks.

The problem of developing terminal benchmarks was more difficult than its batch counterpart and was divided into three subproblems:

(1) Selecting a set of programs that were "typical" of user jobs,

(2) developing terminal scripts to call the programs, and

(3) assigning scripts (type and number) to each terminal in order to apply realistic benchmarking loads to the system.

The benchmark development was further hampered by the fact that reliable statistics on program utilization was not available for these time sharing systems - as is usually the case.

The programs selected for the benchmark were of three types: compilation, execution and edit programs. The compilation programs included a Fortran compilation, because that represented the major portion of terminal jobs at this installation, and a small and a large PL/I compilation. PL/I programs were chosen because they represent large complex compilations which have large working sets (30 to 40 pages) and use large amounts of CPU time, thus degrading the performance of any time sharing system.* The execution programs were represented by a computer-bound (Fortran) execution program and a page-bound (Fortran) execution program. The edit program was a simple program that performed some typical editing functions and then waited for a "simulated think time" period. The actual programs used in the benchmark were as follows:

*It is believed that the large PL/I jobs are representative of other heavy demand jobs such as assembler programs, large programs with many subroutines, etc.

FORTRAN - A routine to compile an average size (75 card) Fortran program.

PLILG - A routine to compile a large (434 card) PL/I program.

PLISM - A routine to compile a small (47 card) PL/I program.

FORTEX - A routine to simulate a compute-bound job. It executed 1,000,000 additions in a loop and then printed a line at the terminal.

PAGE - A routine that uses a large array and accesses a different page for each operation.

EDIT - A routine that performs several edit type functions, such as locating a string in the program, moving the pointer up and down and typing some output to a terminal.

The major difficulty in selecting the programs was for the EDIT program, since each time sharing system handled editing differently. TSS stored the results after every edit command onto backup storage (disk or drum), while CP and MTS stored the editing results only when told to "SAVE". Since the TSS operation could not be changed, it was decided to make CP and MTS more consistent with TSS by having their edit programs retrieve and store the file after executing a few edit commands. The other problem with edit programs was in simulating a time delay to represent "think time". The basic idea was to execute edit commands for about 5 seconds and then to wait for 55 seconds for "think time". For TSS, a built-in real time clock was used to represent the 55 second delay by causing an interrupt. For CP the delay was produced manually by a terminal operator who restarted the editor every 55 seconds and allowed it to run for 5 seconds. For MTS, the delay was simulated by having the editor print an extra ten lines at the terminal. In actual fact, the MTS edit program printed 19 lines (9 extra) compared to two for CP, again, because of differences in the editors.

After the programs were selected for the terminal benchmarks, the next subproblem was to develop the proper terminal scripts for calling the programs. The major concern was whether to run fixed scripts - where each terminal script ran one and only one program -, or mixed scripts - where each script called several programs in some predetermined order. The fixed script approach was selected because it allowed better load control and data analysis. (It was later verified that the mixed scripts produced approximately the same response for the same load as the fixed scripts.)

The scripts were each written so that they would print the starting time at the terminal, call the program, print the completion time and then repeat by calling itself. This minimized the test operator intervention - limiting it to changing the scripts of certain terminals at the beginning of each run. Complete listings of the program and the terminal scripts are shown in Appendix A.

The third subproblem in defining terminal benchmarks is to assign the scripts (number and type) to each terminal. Early in the testing, it was decided to hold the number of terminals relatively constant at about 24 and to vary the load by adjusting the ratios of each type of script. Thus a test with many edits and only a few large PL/I or paging jobs would be a light load. In fact, a wide range of loads from light to very heavy loads was obtained by changing the ratio of edit scripts to compilation-plus-execution scripts from 5:1 to 1:5. The ratio 2:1 probably best represents the normal user load but the heavier loads were used to test the system tolerance to overload. The actual number of each script for each test run is given in the next section (Section 3).

The major difficulty in selecting the number of each scripts to represent a desired load is that the different schedulers (the resource allocators in the operating systems) handle the same type of job differently. For example, MTS has a very effective strategy for handling compute-bound jobs - by assigning them a large time slice on the second processor -, and for handling "trouble-makers" who want a large number of pages and a lot of CPU time - by assigning them to the back of a low priority queue (possibly after giving them one long time slice). This seriously changes the effective load on the system, even when the terminals are running identical scripts. This is discussed further in the results section.

2.2.2 Batch Benchmarks

The batch benchmarks, that were used for comparing the batch operation of TSS, OS and MTS, consisted of fifteen programs arranged to make 3 separate benchmarks. The 15 programs were all three-step or four-step Fortran jobs with 12 of the jobs requiring less than 25 seconds of CPU time and less than 100K bytes of core memory, while the other three required less than 6 minutes and 300K bytes of memory. The characteristics of the programs are given in Appendix B. A complete listing of the programs can be obtained from the author.

The batch programs were organized in three benchmarks as follows:

(1) Benchmark A - compilations with source listings,

(2) Benchmark B - compilations without source listings, and

(3) Benchmark C - No compilation or listings, i.e., programs run from load modules on disk. Data (and Job Control Language) was still read from card reader.

The test method for using the batch benchmarks was to put all the card decks in the card reader with the computer idle waiting for input, start the card reader and then record the time from the first card read until all the jobs were processed and the last line printed.

2.3 Possible Methods of Measuring Performance

Two basic methods for measuring computer performance are:

(a) Primary Performance - performance as seen by the user, i.e., turnaround time, terminal response time and sometimes throughput. Primary performance is sometimes referred to as external performance.

(b) Secondary Performance - performance as observed within the computer itself, i.e., CPU utilization, channel utilization, memory utilization, paging rates, overhead, number of I/O operations, and sometimes throughput. Secondary performance is also referred to an internal performance.

There are several methods of measuring both primary and secondary performance. Primary performance can be measured by a stopwatch, by an elapsed-time clock in the computer or by users' dissatisfaction (or screams). Secondary performance can be measured by a software monitor or a hardware monitor.

The major advantages of primary performance over secondary performance is the relative ease of making the measurements and the fact that primary performance is one of the major criteria in selecting a computer operating system. Another advantage, of somewhat lesser significance, is that the measurements are easy to make and require relatively little data analysis. For these reasons, primary performance measurements were used almost exclusively in this project.

This is not to suggest that hardware and software monitors are not important - in fact several have been used at NPS* - but for the main objective of the project, which was to assist management in selecting the best operating system, the primary performance measurements were more significant than hardware and software monitor measurements. Furthermore, considering the large number of configurations and loading methods to be evaluated, the smaller amount of data analysis was significant.

2.4 Actual Measurements Performed

As stated above, most of the measurements presented in this report were primary performance measurements. The primary performance measurements used were the terminal response times and the throughputs (or job completion rates) for terminal loads, and total completion times for batch benchmark tests. For terminal tests, a built-in elapsed-time clock was used to print the starting times and the finishing times on the terminals. The initiate-to-completion times for the batch jobs were measured with a stopwatch.

*For example, a hardware monitor by Boole and Babbage called the Measurement Engine has been used to measure OS [8,9], while the following software monitor have also been used: SIPE for TSS [10,11], MEASURE (New York State University, Stonybrook [12], and CPSNOOP (University of Alberta, Canada) for CP [13], SUPERMON, PROGLOOK and SMF (accounting data) for OS, and the Data Collection Facility for MTS.

In some cases the secondary performance such as percentage of time in problem state and paging rates were also recorded and are reported later. In some other cases software monitor measurements were made but not analyzed or included in the report.

Section 3

BENCHMARK TESTS PERFORMED

3.1 Terminal Benchmark Tests

All together about 60 terminal benchmarking test runs were made involving more than 38 hours of dedicated computer time. Of these, 38 produced useful results and are reported here. These reported runs include 22 runs for CP, 9 for TSS and 7 runs for MTS. Since each run had definite script assignments which represented a definite load (or benchmark), whenever the same script assignments were run on two different operating systems the runs were useful benchmarks for comparing the computer performance of the different operating systems. The terminal benchmarking runs involved calling the terminal scripts described previously in subsection 2.2.1.

Most of the test runs were performed on CP - primarily because of its extensive use and easy availability at NPS. The 22 CP test runs (plus 3 preliminary runs) are shown in Table 2 - which shows the script assignment for all runs. Runs R11, R12 and R13 were preliminary runs used to develop the scripts and the benchmarking procedures. Since they did not produce any useful results, they were usually excluded from the analysis in the later sections.

The runs in Test 2 (those beginning with the digit 2) were conducted with approximately a 2:1 ratio of edit to compilation-plus-execution scripts and with a variable number of terminals. These runs were intended as a realistic representation of the actual terminal user loads experienced

TABLE 2: SUMMARY OF CP BENCHMARK RUNS

	R11	R12	R13	R21	R22	R23	R24	R25	R31	R32	R33	R34	R35	R41	R42	R43	R44	R45	R46	R47	R51	R52	R53	R54
EDIT	2	7	7	8	10	12	14	15	4	12	10	8	6	14	13	10	7	0	0	13	15	0	0	15
PAGE	0	0	0	0	0	0	0	0	0	0	2	4	6	0	0	0	0	0	0	0	0	2	1	0
FORTEX	1	4	4	3	2	3	3	4	6	2	2	2	2	5	6	6	6	5	4	6	5	5	5	5
PLISM	0	0	0	0	0	0	0	1	3	3	3	3	3	1	1	1	1	1	2	1	1	1	1	1
PLILG	1	3	2	0	0	1	1	1	4	2	2	2	2	1	1	4	7	14	14	1	1	14	15	1
FORTRAN	0	0	1	1	1	1	3	1	7	5	5	5	5	1	1	1	1	2	2	1	1	1	1	1
TOTAL TERMINALS	4	14	14	12	13	17	21	22	24	24	24	24	24	22	22	22	22	22	22	22	23	23	23	23
CP LOAD FACTOR*	16	54	50	32	32	48	60	64	110	86	130	174	218	66	68	86	104	146	148	68	68	190	174	68
COMBINED LOAD FACTOR*	16	55	49	28	24	40	46	55	204	68	36	104	122	60	65	86	107	152	152	65	61	170	168	61

*See Section 4 for calculation of Load Factor under normal operations. The runs in Test 3 were conducted with much lower ratio of edit to compilation-plus-execution jobs than Test 2 - as low as 1:4 - with a constant 24 terminals. These runs represented much heavier loads than those in Test 2 and were designed for comparing the computer performance under heavy overload conditions. Test 4 was designed for testing the performance in the range between Tests 2 and 3, and for determining the overload recovery time. Test 5 represents another rather heavy load similar to Test 4. It also included some mixed script tests to be reported later.

The 9 TSS runs were designed to be the same as the runs in Tests 2 and 3 for CP. Since the runs are almost identical the same run identification numbers were used as shown in Table 3. Table 3 also shows the terminal script assignments for all the TSS runs. More tests were planned for TSS but after analyzing the results from these tests it was decided to discontinue the TSS evaluation.

The 7 MTS runs were designed to cover the complete range of the CP runs, providing the response time remained below the predetermined maximum limit of 20 minutes for a PLILG. Table 4 shows the terminal script assignment for the MTS runs. The MTS runs actually covered the complete spectrum of CP tests;but unfortunately, due to an error in the terminal assignments during the test, the MTS runs did not match the CP runs exactly. Therefore the closest CP run and the degree of closeness are also shown in Table 4.

TABLE 3: SUMMARY OF TSS BENCHMARK RUNS

Script \ Run ID	R21	R23	R24	R25	R31	R32	R33	R34	R35
EDIT	8	12	14	16	4	12	10	8	6
PAGE	0	0	0	0	0	0	2	4	6
FORTEX	2	3	3	4	6	2	2	2	2
PLISM	0	1	0	1	3	3	3	3	3
PLILG	1	1	1	0	4	2	2	2	2
FORTRAN	1	1	3	3	7	5	5	5	5
Total	12	18	21	24	24	24	24	24	24

TABLE 4: SUMMARY OF MTS BENCHMARK RUNS

Script \ Run ID	R61	R62	R63	R64	R65	R66	R67
EDIT	11	13	10	8	8	5	12
PAGE	0	0	0	0	2	0	0
FORTEX	3	4	4	4	3	6	0
PLISM	0	1	1	1	3	3	1
PLILG	1	4	7	4	4	4	7
FORTRAN	1	1	1	1	3	5	3
TOTAL	16	23	23	18	23	23	23
MTS LOAD FACTOR*	44	84	142	84	97	132	113
CLOSEST CP TEST	R23	R43	R44	R42	R33	R31	R44
DEGREE OF CLOSENESS TO CP TEST	Good	Good	Close	Poor	Poor	Good	Close

*See Section 4 for calculation of Load Factor

Unfortunately there were a limited number of runs on which direct performance comparisons can be made. There were 9 runs from Tests 2 and 3 for comparing CP and TSS. There were 5 reasonably good comparison runs for CP and MTS, although there were some minor differences in the script assignments. These differences were insignificant compared to the difference in effective load and resulting difference in performance. There were only 3 runs for comparing all three systems, but that need not hamper the comparisons of pairs of systems and the inferred comparison of all three systems.

Table 5 shows all the terminal benchmark runs with similar runs grouped together for easy comparison of minor differences in the benchmarks.

3.2 Batch Benchmark Tests

The batch benchmarking tests consisted of running the three batch benchmarks described in Section 2.2.2 on the three operating systems with batch handling capabilities - TSS, OS, and MTS. The TSS evaluation tests were conducted with the full duplex (2 processors) and the half duplex (single processor) configurations, both with three core boxes, and then with the half duplex configuration with two core boxes. OS/MVT was evaluated with a single processor configuration with two and three core boxes. (Duplex operation is impossible under OS.) MTS was tested under all three batch benchmarks with duplex, three-core box configuration, but only under Benchmark C with the single processor, two-core box system.

3.3 Other Tests

The indirect synthetic job, called CPTEST, has been used at NPS for some evaluation of CP under normal operating conditions but has not been used for terminal benchmarking. However the same program has been used

TABLE 5: COMPARISON OF TERMINAL BENCHMARKING RUNS

Run Number	Operating System	TERMINAL SCRIPTS						Total Terminals	Load Factor**
		EDIT	FORTEX	FORTRAN	PLISM	PLILG	PAGE		
R21*	TSS	8	2	1	0	1	0	12	28
	CP	8	3	1	0	0	0	12	32
R22*	TSS								
	CP	10	2	1	0	0	0	13	32
R23	TSS	12	3	1	1	1	0	18	40
	CP	12	3	1	0	1	0	17	48
R61	MTS	11	3	1	0	1	0	16	44
R24*	TSS	14	3	3	0	1	0	21	46
	CP	14	3	3	0	1	0	21	60
R25*	TSS	16	4	3	1	0	0	24	55
	CP	15	4	1	1	1	0	22	64
R31	TSS	4	6	7	3	4	0	24	104
	CP	4	6	7	3	4	0	24	110
R66	MTS	5	6	5	3	4	0	23	132
R32*	TSS	12	2	5	3	2	0	24	68
	CP	12	2	5	3	2	0	24	86
R33	TSS	10	2	5	3	2	2	24	86
	CP	10	2	5	3	2	2	24	130
R65	MTS	8	3	3	3	4	2	23	97
R34	TSS	8	2	5	3	2	4	24	104
	CP	8	2	5	3	2	4	24	174
R35	TSS	6	2	5	3	2	6	24	122
	CP	6	2	5	3	2	6	24	218
R36	CP***	4	6	7	3	4	0	24	110

*No equivalent MTS run

**See Section 4 for calculation of Load Factors. CP Load Factor for CP, Combined Load Factor for TSS and MTS Load Factor for MTS.

***CP with 2 core boxes. Same benchmark as Run R31. (All other CP runs with 1 core box.)

TABLE 5: COMPARISON OF TERMINAL BENCHMARKING RUNS (Continued)

Run Number	Operating System	TERMINAL SCRIPTS						Total Terminals	Load Factor**
		EDIT	FORTEX	FORTRAN	PLISM	PLILG	PAGE		
R41	CP	14	5	1	1	1	0	22	66
R42	CP	13	6	1	1	1	0	22	68
R64	MTS	8	4	1	1	4	0	18	84
R43	CP	10	6	1	1	4	0	22	86
R62	MTS	13	4	1	1	4	0	23	84
R44	CP	7	6	1	1	7	0	22	104
R63	MTS	10	4	1	1	7	0	23	142
R67	MTS	12	0	3	1	7	0	23	113
R45	CP	0	5	2	1	14	0	22	146
R46	CP	0	4	2	2	14	0	22	148
R47	CP	13	6	1	1	1	0	22	68
R51	CP	15	5	1	1	1	0	23	68
R52	CP	0	5	1	1	14	2	23	190
R53	CP	0	5	1	1	15	1	23	174
R54	CP	15	5	1	1	1	0	23	68
Load Factor Weights**	CP	2	4	4	6	8	24		
	MTS	1	8+	1	6	8+	6		
	Combined	1	6	2	6	8	10		

+Weights for ≤4 jobs; weight = 20 for the number of jobs above 4.

extensively at the University of Alberta for benchmarking the performance of CP and MTS [6].

Two other types of tests were conducted involving the use of a terminal probe for measuring the normal terminal response under actual operating conditions, and involving the running of mixed scripts to verify that they produced approximately the same terminal responses as the fixed scripts used for benchmarking. These tests, along with the results, are described in Section 5.

Section 4

DATA COLLECTION AND ANALYSIS

4.1 General Philosophy

Most of the data collected and analyzed in this project was the primary performance measurements as discussed previously in Sections 2.3 and 2.4. For the terminal benchmarking runs, the primary performance measurements included the terminal response times and the throughputs or job completion rates. For the batch benchmarking runs, the primary performance measurements were the total elapsed job completion times.

The terminal response times were collected by having the terminal scripts print the real time (wall clock time) at the commencement and completion of the programs called by the scripts. The terminal response times were extracted manually from the terminal printouts. From these figures the mean response time for each terminal was determined. These mean terminal response times, organized by script, are shown in Appendix C. The mean response time per script was determined by averaging the mean terminal response times for each script. These results were used to prepare many of the TSS and MTS graphs presented in Section 6. For CP mean terminal response times were used instead of mean response times per script.

The job completion rates, or throughputs were determined by counting the number of program completions and dividing by the length of the run. The actual throughput calculations are discussed further in the next section.

For the batch benchmarking runs, the primary performance was measured by recording the starting time for reading of the first card and the completion time for printing the last line on the line printer. In some cases other times were also determined, such as, the elapsed time for completion of individual jobs or the elapsed time while the system was fully loaded. These times were determined from the operator's console log or from the accounting information appearing on the printout.

4.2 Throughput Analysis

Two types of throughput are defined in this section: measured throughput and calculated throughput. The measured throughput was determined by observing the number of job (or program) completions during the run and dividing that figure by the run duration. The calculated throughput is determined by the reciprocal of the mean terminal response time for that script.

4.2.1 Measured Throughput

The measured throughput was determined by counting the number of job completions of a given type within a test run and dividing by the total elapsed time of the test. This measured throughput was recorded in jobs per minute per terminal for each job type (script) for each run.

The formula for determining the measured throughput on a terminal was:

$$TP^{m}_{ij} = SS_{ij}/RD \tag{1}$$

where TP^{m}_{ij} = measured throughput of script i on terminal j

SS_{ij} = Number of script i that completed on terminal j, i.e., the sample size

RD = Run duration

The total throughput for all terminals running script i was:

$$TP_i^m = \frac{1}{RD} \sum_{j=1}^{NT_i} SS_{ij} , \tag{2}$$

where NT_i = number of terminals running script i.

The mean throughput of all terminals running script i was simply:

$$TP_i^m = \frac{1}{RD \times NT_i} \sum_{j=1}^{NT_i} SS_{ij} . \tag{3}$$

On the other hand, by counting all the jobs that completed for script i regardless of the terminal (called SS_i), the mean measured throughput formula for script i was reduced to

$$TP_i^m = SS_i/(RD \times NT_i) . \tag{4}$$

Note that jobs that were completed before the test started or jobs that had not completed by the end of the run were generally* not included in the sample size.

The total measured throughput was calculated by:

$$TP^m = \sum_{i=1}^{6} TP_i^m \tag{5}$$

4.2.2 Calculated Throughput

On the other hand, the calculated terminal throughput per minute was defined as the reciprocal of the mean response time for each script:

*In a few cases where the sample size was small (i.e., very heavy loads most of the job completion time was between the run start and stop times, the job was included in the sample size.

$$TP^c_{ij} = 1/RT_{ij} \ , \tag{6}$$

where RT_{ij} was the mean response time for script i on terminal j.

The calculated throughput for each script (regardless of terminal) was:

$$TP^c_i = \sum_{j=1}^{NT_i} \frac{1}{RT_{ij}} \ , \tag{7}$$

where NT_i = the number of terminal running script i. When the response time for each script on each terminal, RT_{ij}, was replaced with the mean response time of all terminals running script i, RT_i, given by:

$$RT_i = \frac{1}{NT_i} \sum_{j=1}^{NT_i} RT_{ij} \ , \tag{8}$$

then the mean calculated throughput for each script was calculated by:

$$\overline{TP}^c_i = 1/RT_i \ . \tag{9}$$

This was actually the formula used in determining the calculated terminal throughput.

The total calculated throughput was determined by

$$TP^c = \sum_{i=1}^{6} NT_i \times \overline{TP}^c_i \tag{10}$$

An alternate method for determining the total calculated throughput per script and the total calculate throughput would be:

$$TP^c_i = \sum_{j=1}^{NT_i} \frac{1}{RT_i} = \frac{NT_i}{RT_i} \ ,$$

or $$TP_i^c = \frac{NT_i}{\frac{1}{NT_i} \sum_{j=1}^{NT_i} RT_{ij}} = \frac{(NT_i)^2}{\sum_{j=1}^{NT_i} RT_{ij}}$$

The total calculated throughput, TP^c, would be calculated by:

$$TP^c = \sum_{i=1}^{6} TP_i^c .$$

This equation is similar to Equation 5 for the total measured throughput, but it was not used in the actual calculations.

4.2.3 Measured verses Calculated Throughput

When the two throughputs were compared, the calculated throughput was always higher than the measured throughput because*:

1) it neglected the partially completed scripts at the beginning and the end of the run, and

2) it neglected the overhead in initiating and terminating the scripts.

The first factor improved the accuracy of the calculated throughput over the measured throughput but the second factor had the opposite effect. Especially at heavy loads, the time to initiate and terminate a script seriously reduced the total number of completions per minute. Thus the actual throughput was between the measured and the calculated throughputs.

*In a few cases minor recording errors reversed this theoretical results.

4.3 Definition of Load Factors

In order to present the data in organized fashion, it was necessary to calibrate the loads presented by the terminal benchmarks. Since the number of terminals was not a good indication of the load, it was necessary to develop a new method of calibrating the loads. In fact, even with a constant number of terminals, the load obviously changed significantly since the terminal response times changed over a range of four to one. These requirements provide the motivation for defining a load factor.

Therefore the load factor was defined as:

$$LF = W_1 N_{EDIT} + W_2 N_{FORTRAN} + W_3 N_{FORTEX} \qquad (11)$$

$$+ W_4 N_{PLISM} + W_5 N_{PLILG} + W_6 N_{PAGE}$$

or more simply as:

$$LF = \sum_{i=1}^{6} W_i N_i , \qquad (12)$$

where N_i is the number of script i being run (i.e., same at number of terminal running script i, i.e., NT_i in the previous section) and W_i is the weight assigned to script i. The value of the weight depends on the loading effect of the script; if W_i is low, that script applies a small load to the system but if W_i is high, that script applies a heavy load. The major problem with the load factor concept is in the determination of appropriate weights.

Since the purpose of the load factor was to present the data in an organized fashion, the load factor weights were initially determined by subjective analysis of the terminal response times and probably loading effects of each type of script used in the benchmarks. A set of weights were arbitrarily chosen and the terminal response times were plotted for each script. Then the weights were adjusted to make all the response time graphs approximate linear functions of the load factor. This was repeated as necessary until the following load factor equations were obtained. The CP load factor (as determined from Figure 2) was:

$$LF_{CP} = 2\ N_{EDIT} + 4\ N_{FORTRAN} + 4\ N_{FORTEX} + 6\ N_{PLISM} + 8\ N_{PLILG} + 24\ N_{PAGE} \qquad (13)$$

The MTS load factor (as determined from Figure 23) was:

$$\begin{aligned} LT_{MTS} = {} & N_{EDIT} + N_{FORTRAN} + 6\ N_{PLISM} + 6\ N_{PAGE} \\ & + 8\ ((N_{FORTEX} \le 4) + 2.5\ (N_{FORTEX} > 4)) \\ & + 8\ ((N_{PLILG} \le 4) + 2.5\ (N_{PLILG} > 4)) \end{aligned} \qquad (14)$$

The extra complexity of the MTS load factor was the result of the sharp increase in the response time with more than 4 jobs of either FORTEX or PLILG scripts.

Although these load factors work very well in presenting the throughput data as well as the terminal response data for the individual systems, they do not work well for comparing the systems. In fact it is obvious that identical terminal loads produce different load factors. Therefore it was necessary to define a third load factor somewhere between the two load factors above. The chosen combined load factor was given by:

$$LF_{COMB} = N_{EDIT} + 2\ N_{FORTRAN} + 6\ N_{FORTEX} + 6\ N_{PLISM} + 8\ N_{PLILG} + 10\ N_{PAGE} \qquad (15)$$

Some interesting results were obtained when the terminal response of one system was plotted against the load factor of another system, which provided some useful insight into the nature of the load factors. When TSS terminal response was plotted against the CP load factor the result was a concave-downward curve as the load factor increased instead of the expected linear relationship. This meant the CP load factor weights were too high for TSS, which meant the CP response was degraded more rapidly the TSS response as the load was increased. On the other hand, when TSS response time was plotted against the combined load factor it produced a linear response relationship. Furthermore when the CP response time was plotted against the combined load factor, the resultant response time curve was a concave-upward function of the load. Thus the load factor actually indicates the load experienced by the computer system as the result of that benchmark. More details of the response times, throughputs and load factors will be presented in Section 6.

4.4 Attempted Regression Analysis

Since the load factors were determined on a rather arbitrary empirical basis, an attempt was made to put the load factor determination on a more firm mathematical basis by using multiple linear regression analysis. Unfortunately this attempt was not successful due to the indirect relationships between the dependent and the independent variables, as explained below. This problem is presented here as an interesting challenge to the reader.

The load factor as given in Equation 12 was:

$$LF = \sum_{i=1}^{6} W_i N_i \qquad \text{(12 repeated)}$$

where N_i is the number of terminal running script i and W_i is the load factor weight assigned to script i. It is assumed that the theoretical terminal response time for each script is some function of the terminal load, say

$$RT_i^t = f(N_i) \tag{15}$$

or $RT_i^t = f(N_{EDIT}, N_{FORTRAN}, N_{FORTEX}, N_{PLISM}, N_{PLILG}, N_{PAGE})$.

The function f could be determined by regression analysis but this was not done. (Actually a linear regression was tried but the required curvi-linear regression was not attempted.) In any case this is not the problem that is of interest.

The main problem is to mathematically relate the terminal response times to the load factors. Assuming for the time being that a linear relationship exists - which is a reasonable assumption considering the definition of the load factor -, then the theoretical response time for script i is:

$$RT_i^t = a_i + b_i \; LF, \tag{16}$$

where a_i is the intercept of the response time curve for script i and b_i is the corresponding slope; and LF is the load factor, or independent variable. Combining Equations 12 and 16 and changing the indices in Equation 12 from i to j produces:

$$RT_i^t = a_i + b_i \sum_{j=1}^{6} W_j \; N_j . \quad \text{for } i = 1 \text{ to } 6 \tag{17}$$

The error between the theoretical and observed response time, RT_i^o , is given by:

$$e_i = RT_i^t - RT_i^o \tag{18}$$

Actually, there is an error for every observed response time (i.e., every benchmark), RT^o_{ik}, which is given by:

$$\begin{aligned} e_{ik} &= RT_i^t - RT_{ik}^o \\ &= a_i + b_i \sum_{j=1}^{6} N_{jk}W_j - RT_{ik}^o , \end{aligned} \tag{19}$$

where N_{jk} is the number of terminals running script j on run k.

The total error E is given by:

$$E = \sum_{k=1}^{NR} \sum_{i=1}^{6} a_i + b_i \sum_{j=1}^{6} N_{jk}W_j - RT_{ik}^o , \tag{20}$$

where NR is the number of runs.

From the CP data there are 22 runs, or sample points, for the observed response time, i.e., k=1 to 22, for each of the 6 scripts making a total of 132 sample points. (Actually there are only about half this number because of the holes in the observed data.) The problem has now been reduced to finding the best values of a_i, b_i and W_j (which is the same as W_i) which minimizes the total error E. Since N_{jk} is the number of scripts j on run k and is known, there are 18 unknowns and about 65 observations. The major complication in minimizing the error is that the b's and the W's appear as the product in the equation.

One method that appears feasible is to replace the $b_i W_j$ product terms by another variable c_m where $m = 1$ to 36. Now the problem is a linear one with 6 unknown variables, a_i, and 36 unknown variables, c_m, and 65 known observations. The follow-on problem would be to separate the c_m variable in product components $b_i W_j$ in order to get the slope of the response time graph and the load factor weights. This is a linear programming problem with 36 equations and 12 unknowns and therefore is relatively simple.

If the reader has any suggestions on how to solve this problem, the author would appreciate hearing about them. In the meantime, the report will proceed using the rather arbitrary load factors described earlier.

Section 5

OTHER TESTS AND INTERMEDIATE RESULTS

5.1 Terminal Mixed Script Tests.

For part of the Test 5 described earlier, mixed scripts were run to confirm the hypothesis that the fixed scripts used in the benchmark tests were a realistic method of loading the computer under evaluation. This test was designed to confirm that mixed scripts produced essentially the same performance as fixed scripts and that the fixed scripts were easier to control and conduct data analysis on. An intermediate load was chosen (Run R44) and three mixed scripts were designed to compare the performance with Test 4 results.

Three scripts were chosen to avoid the cycling problem whereby the same type of programs had a tendency to become synchronized in their request for resources. For example a program that required a lot of processor time while other programs were requiring channel and drum resources for paging would run very quickly (no one else wanted the CPU) and soon get to a part of its script that required a lot of pages; and then it would have to compete with all the other jobs for channel and drum resources. It would then be synchronized with the other jobs.

The same number and type of programs were included in all three scripts, but the order of execution was different. The precise scripts are shown in Appendix A as ALL1, ALL2 and ALL3.

5.2 Terminal Mixed Script Results

Since fixed scripts were easier to control, produced results that were easier to analyze, and made computer performances easier to compare, it was conjectured that fixed scripts could be used in place of the more general mixed scripts. Table 6 shows a comparison of the response to four programs during fixed scripts runs and mixed script runs. Although the mean values of the responses are very close to those of the run from which the mixed scripts were derived (Run 44), there was a lot of variation in the mixed script responses. Sometimes the minimum response was about one-third of the mean value while the maximum was 3 times the mean response. In fact the minimum response for mixed scripts is quite close to run R42, while the maximum responses indicate the load was higher than any used in the benchmarking runs (see Table 6). The fixed script responses are taken from Table C2 in Appendix C.

The load factor that corresponds to the mixed script responses is also shown in Table 6. The minimum and mean responses correspond to load factors of 68 and 106 respectively while the maximum responses represent a load factor of over 200. These correspond very well to the load factors for R42, R44 and R34. The load factors were determined from the terminal response curves to be shown in Figure 2 in Section 6.

The above evidence justified the use of fixed scripts for benchmarking. The evidence showed that the load variance within a run using fixed scripts was much less than for mixed scripts, and that both types of scripts, produced approximately the same mean response times.

Table 6 Results of Mixed Script Tests and a Comparison with Fixed Script Results

Script	Mixed Script Response (minutes)			Fixed Script Mean Responses* (minutes)			Load Factor for Mixed Script Responses**		
	Min.	Mean	Max.	R42	R44	R34	Min.	Mean	Max.
FORTRAN	1.4	3.5	7.2	1.27	2.40	5.17	65	105	>200
FORTEX	4.0	9.7	23.0	5.09	10.5	--	60	100	>200
PLISM	4.3	10.2	27.6	3.63	5.85	14.4	65	105	>200
PLILG	12.2	20.8	45.6	11.4	19.9	40.6	80	115	190
Average CP Load Factor				68	104	174	68	106	>200
Percentage Problem time		35		42	29	7.6			
Page reading rate (per min.)		20.7		23.5	20	32			

* Fixed Script responses are obtained from Table C2 in Appendix C.

**The load factors are taken from the terminal response curves to be shown in Figure 2 in Section 6.

5.3 Terminal Probe Tests

The purpose of the terminal probe tests was to confirm that the benchmark loads were a realistic representation of the actual terminal loads under normal operating conditions. The terminal probe tests were designed to sample the actual response under normal operating conditions. Since the terminal probe was only one of many (7 to 21) normal terminal users and since its effective load was roughly known from the mixed script runs, the effect of the terminal probe on measured performance was to add another "rather typical" user.

A total of 25 terminal probe runs were made on CP on a daily basis over the period April 28, 1971 to June 4, 1971. The terminal probe script is a combination of the same six programs used in the terminal benchmark (See section 2.2.1). The exact script is shown in Appendix A under the name MIX.

5.4 Terminal Probe Results

The terminal probe tests confirmed that the terminal benchmarks represented realistic terminal loads. As conjectured, the actual computer load, as measured under normal operating conditions by the terminal probe tests, was approximately equivalent to runs R21 to R25. At times the measured load was almost as high as the medium heavy loads like R32, R41, R42, R43, etc, but it was never as high as that applied by the heavy overloads on some of benchmark runs.

The results of the 25 daily samples of the normal load are summarized in Table 7. The mean response times were: for FORTRAN, 0.42 minutes; for PLISM, 3.4 minutes; and for PLILG, 4.5 minutes. The corresponding maximum

Table 7 Results from Terminal Probing Tests

	Response Times (minutes)				Corresponding Load Factors from Figure 2 Section 6		
Script	Minimum	Mean	Maximum	Standard Deviation	Minimum	Mean	Maximum
EDIT	.033	.19	1.0	.27	<30	40	>70
FORTRAN	.12	.42	1.37	0.39	<40	52	65
FORTEX	.38	1.28	4.1	1.04	20	45	62
PLISM	.5	3.4	11.1	2.7	25	55	110
PLILG	1.15	4.5	15.0	2.9	20	50	90
PAGE	1.57	4.4	11.1	2.4	--	--	--
2nd EDIT	.033	.26	.97	.25	<30	50	>70
TOTAL	6.8	16.2	36.2	7.2			
PAGE (scaled)*	6.5	18.1	45.8	9.6			
TOTAL (scaled)*	11.9	29.9	71.7	--			
Mean Load Factor					≤25	50	80

*Scaling because main loop in PAGE was decreased by a factor of 4.1 from 1030 to 250 in order to reduce the total response time. (Size of matrices stayed the same.)

response times were: for FORTRAN, 1.4 minutes; for PLISM, 11.1 minutes; and for PLILG, 15.0 minutes. The load factors corresponding to the average actual computer load and to the maximum sampled actual load are 50 and 80 respectively. (These load factors were determined from Figure 2 in Section 6.) Since the benchmarking tests had load factors of 30 to 200, the benchmarking runs do, in fact, represent normal, heavy and very heavily overloaded conditions.

In order to determine values for the combined load factor and the MTS load factor that were representative of the normal user loads and the heaviest sampled user loads, a plot was made of combined load factor and MTS load factor versus CP load factors for all the benchmarking runs. From this graph, the corresponding values of 45 and 46 for the normal user load and 70 and 74 for the heaviest sampled load were obtained for the combined load factors and the MTS load factors, respectively. These values are summarized in Table 8.

Table 8 MTS and Combined Load Factors Corresponding to the Normal User Loads

		Average Sampled User Load	Heaviest Sampled User Load
CP Load Factor		50	80
Corresponding Combined Load Factor	Range	38 to 52	57 to 84
	Mean	45	70
Corresponding MTS Load Factor		46	74

Section 6

RESULTS AND COMPARISONS

6.1 General Philosophy

This section presents the results of more than 38 terminal benchmarking runs and 22 batch benchmarking runs, together with the performance comparisons of four computer operating systems over a wide variety of loading conditions. The terminal response times, terminal throughput rates, total effective progress rates and batch processing turnaround times are compared under several different conditions. The subjects discussed in this section include the presentation of the CP test results, the TSS test results, the CP and TSS comparisons, the MTS test results, the CP and MTS comparisons, the CP, TSS and MTS comparisons - all under terminal loads -, followed by the batch test results and, finally, the TSS, MTS and OS comparisons under batch loading.

The terminal benchmarking results and comparisons include the terminal response times for each script and the measured and the calculated throughputs and the effective progress rates over a wide range of loading conditions. Sometimes the results are presented as average per terminal, per script or as a total over all scripts. For CP the percentage of problem time and paging rates are presented as secondary performance results.

The batch benchmarking results and comparison include the elapsed time to complete the three benchmarks under various configurations of TSS, MTS and OS.

On the other hand, the preliminary results of the mixed script tests and the terminal probe tests are presented previously in Section 5. The results include a performance comparison with mixed script loading and with fixed script loading as used in the benchmarking tests, and the comparison of the benchmarking loads with the normal terminal loads that exist under actual operating conditions.

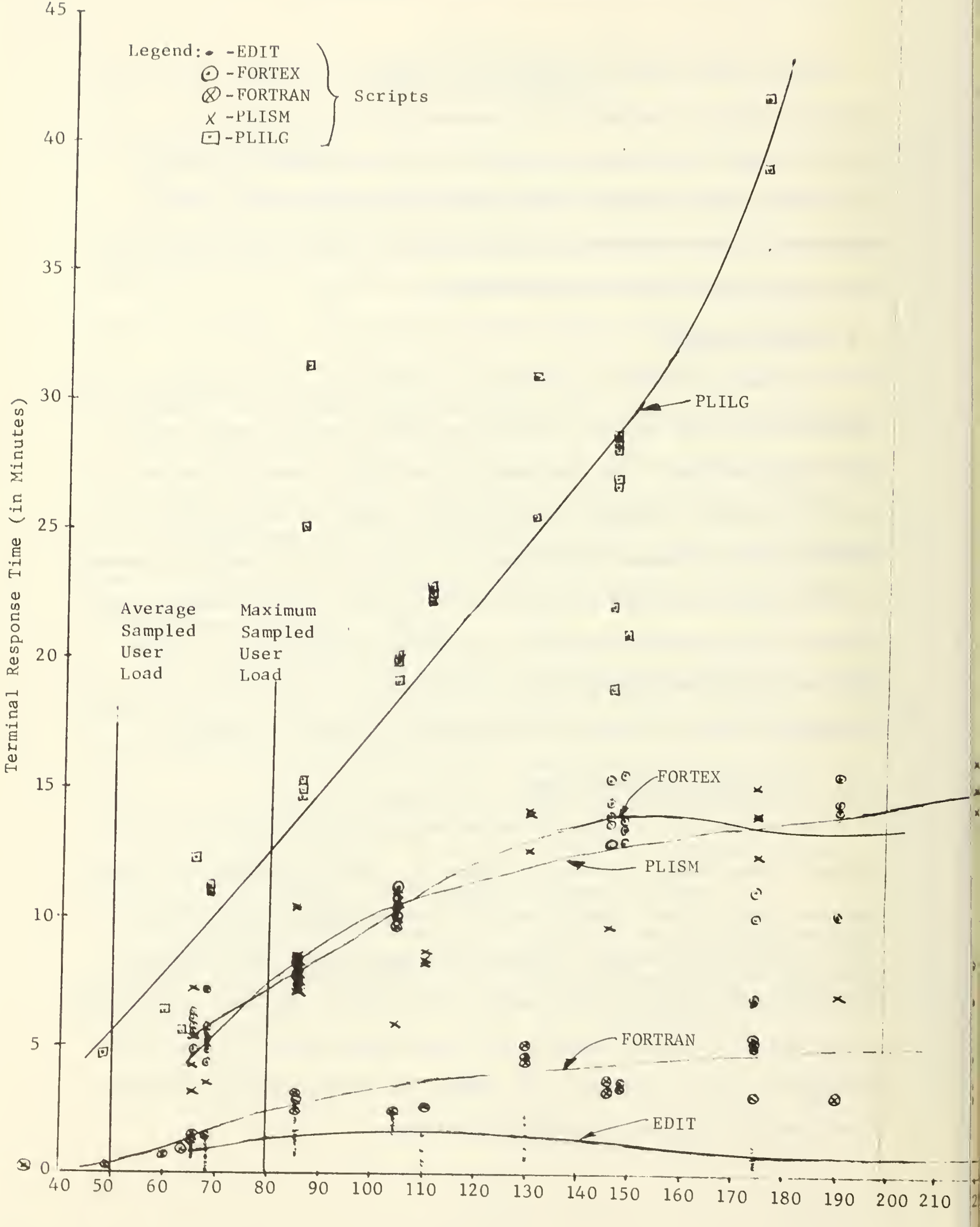
6.2 CP Test Results

This section presents the results of 22 CP terminal benchmarking runs representing a wide variety of loads from fairly typical normal loads to very heavy overloads. The assignment of scripts to terminals for each run are presented previously in Section 3.1, while the description of the scripts and the programs are in Sections 2.2.1 with the listing in Appendix A. The results presented in this section include terminal response times, measured and calculated throughputs, effective progress rates, problem time percentages and paging rates. The results are almost always presented in graphical form; the numerical equivalents are shown in Sppendix C.

6.2.1 CP Terminal Response Times

The CP terminal response times for various CP load factors for all scripts (except PAGE) are shown in Figure 2. The data plotted is the mean response time for each terminal and as shown in Table C1 of Appendix C for each run, the PLILG response increases the most rapidly and is almost a linear function of the CP load factor. Of course the linearity is partially due to the method of defining the load factor but, since the consistency of points is not a function of the chosen load factor, the PLILG response curve serves to support the load factor concept.

Figure 2: CP TERMINAL RESPONSE TIME FOR EACH SCRIPT UNDER VARIOUS LOADS



The FORTEX and PLISM response times are approximately the same and they are the second and third highest curves. The FORTRAN response times curve are next and are quite flat, especially for load factors above 140. The EDIT response time is the lowest and is the only one that peaks at an intermediate load, i.e., at load factor equal to 100.

6.2.2 CP Measured Throughputs

The CP measured terminal throughput for each script for various loads is shown in Figure 3. The FORTRAN mean throughput drops the most rapidly from 0.6 jobs per minute at a load factor of 70 to 0.1 jobs per minute at a load factor of 200. FORTEX,PLISM and PLILG all have a gradually decreasing throughput with increasing load. The EDIT throughput remains approximately constant over all loads with a small dip near 100.

The total measured throughput for all terminal running a particular script is shown in Figures 4 and 5. The data presented in these graphs was obtained by multiplying the average throughput for each terminal (as shown in Figure 3) by the number of terminals running that script. The wide variation in throughput per script for any particular load is the result of a shifting of the load percentage in favor of a particular script (and therefore the resources allocated to the script) as the number of terminals running that script is changed. For example, if a large number of terminals are assigned PLILG scripts (i.e., 14 on Run R45 with a load factor of 146), then a large percentage of the total computer resources are assigned to PLILG scripts and the resulting total PLILG

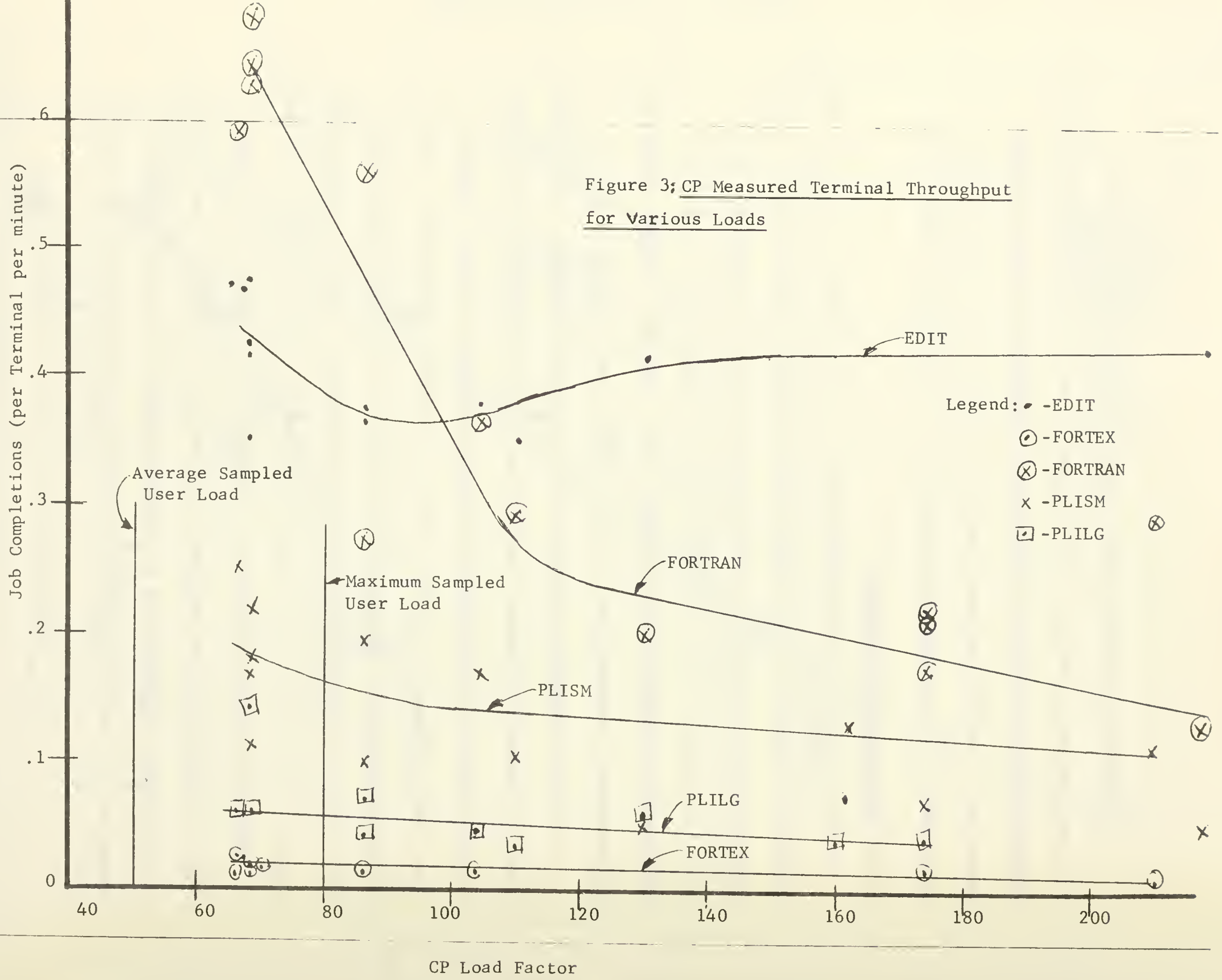
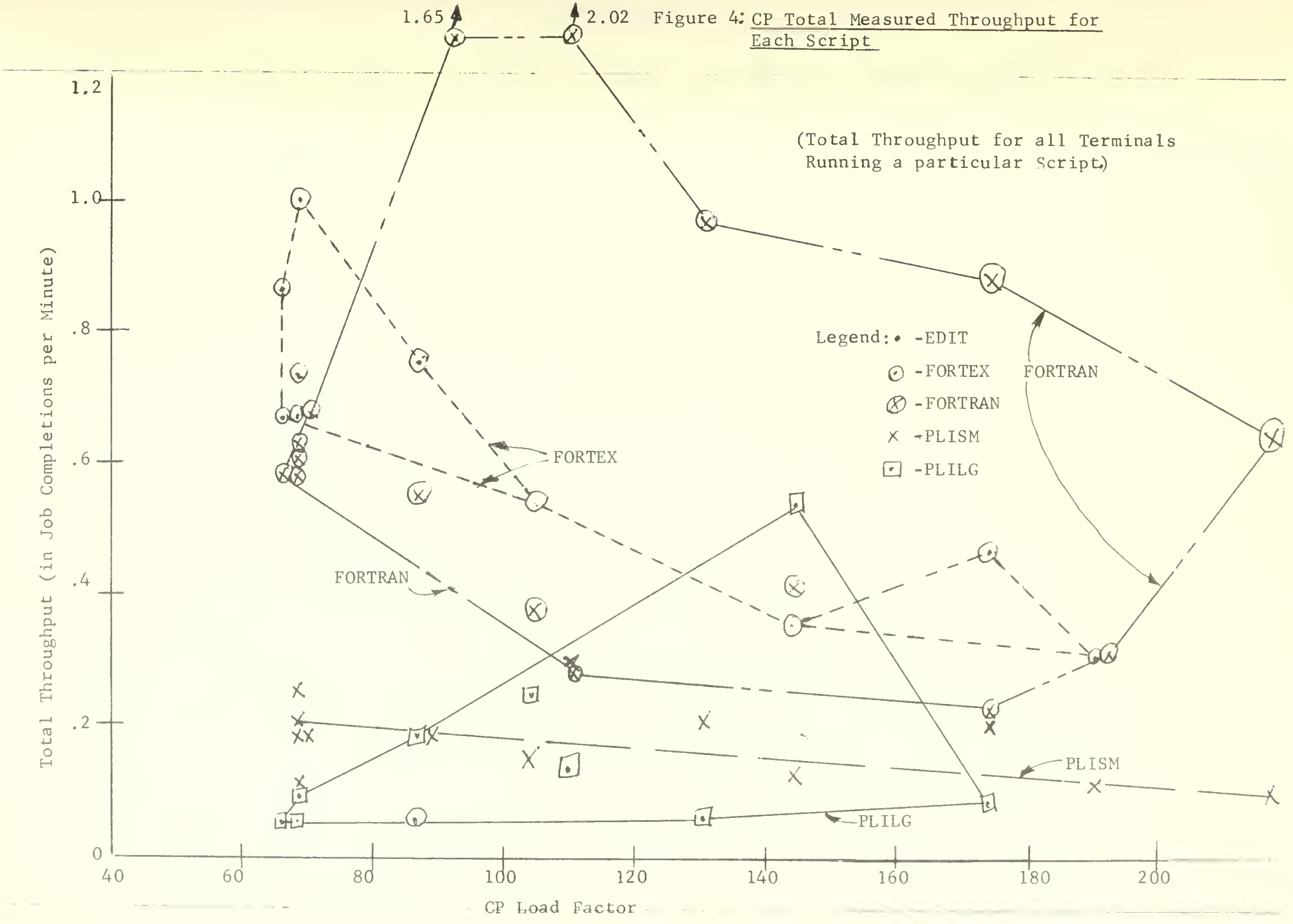


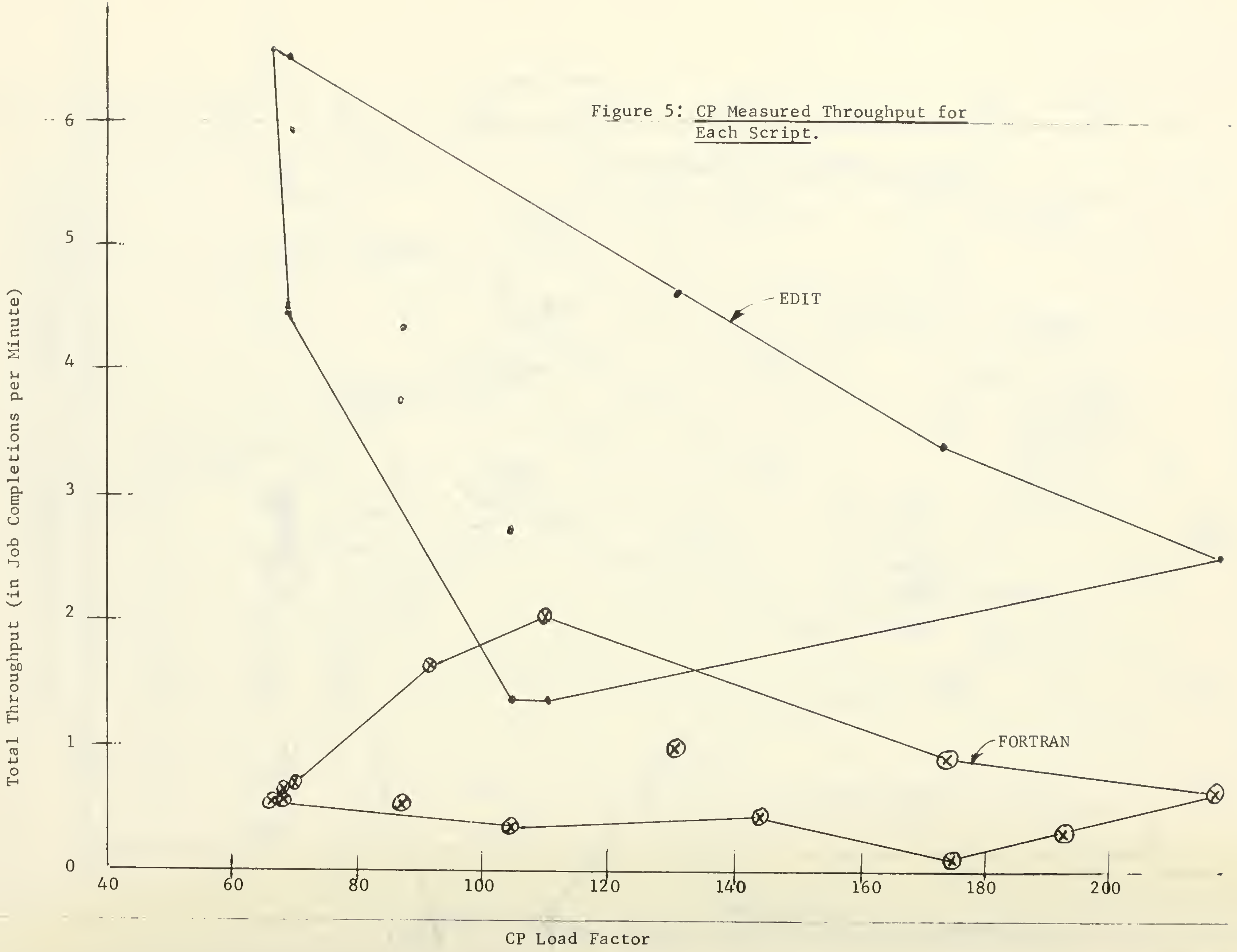
Figure 3; CP Measured Terminal Throughput for Various Loads

Figure 4: CP Total Measured Throughput for Each Script



(Total Throughput for all Terminals Running a particular Script)

Figure 5: CP Measured Throughput for Each Script.



throughput is large. Since there is such a wide variation in throughput, the "envelop-type" graphs have been used in several cases on Figures 4 and 5.

The total measured throughput for CP is shown in Figure 6. The total measured throughput was calculated by adding the five total measured throughput per script (as shown in Figures 4 and 5).

The total throughputs for two weighting factors are also shown in Figure 6. For example, the curve for the CP load factor weighted throughput is determined by:

$$TP = \sum_{i=1}^{6} \omega_i \, TP_i$$

where ω_i is the CP load factor weight for script i and TP_i is the total throughput for script i from Figures 4 and 5. Thus a script such as PLILG which has a large load factor weight and low throughput rate has its total throughput multiplied by a large factor. As can be seen from Figure 6 the extra weighting for the heavy loading jobs has little affect on the shape of the total throughput curves.

6.2.3 CP Calculated Throughputs

The CP mean calculated throughputs were determined using Equations 8 and 9 in Section 4. The CP mean calculated terminal throughputs are plotted in Figures 7 and 8 using the dashed lines. The throughputs for EDIT and FORTRAN scripts are shown in Figure 8 on a larger scale. The PLISM and EDIT throughputs varies significantly and are shown using envelop graphs.

Also shown on Figures 7 and 8 are the measured terminal throughput curves (not individual points) in solid lines, so that they may be compared to the

Figure 6. CP Total Measured Throughput with Various Weighings

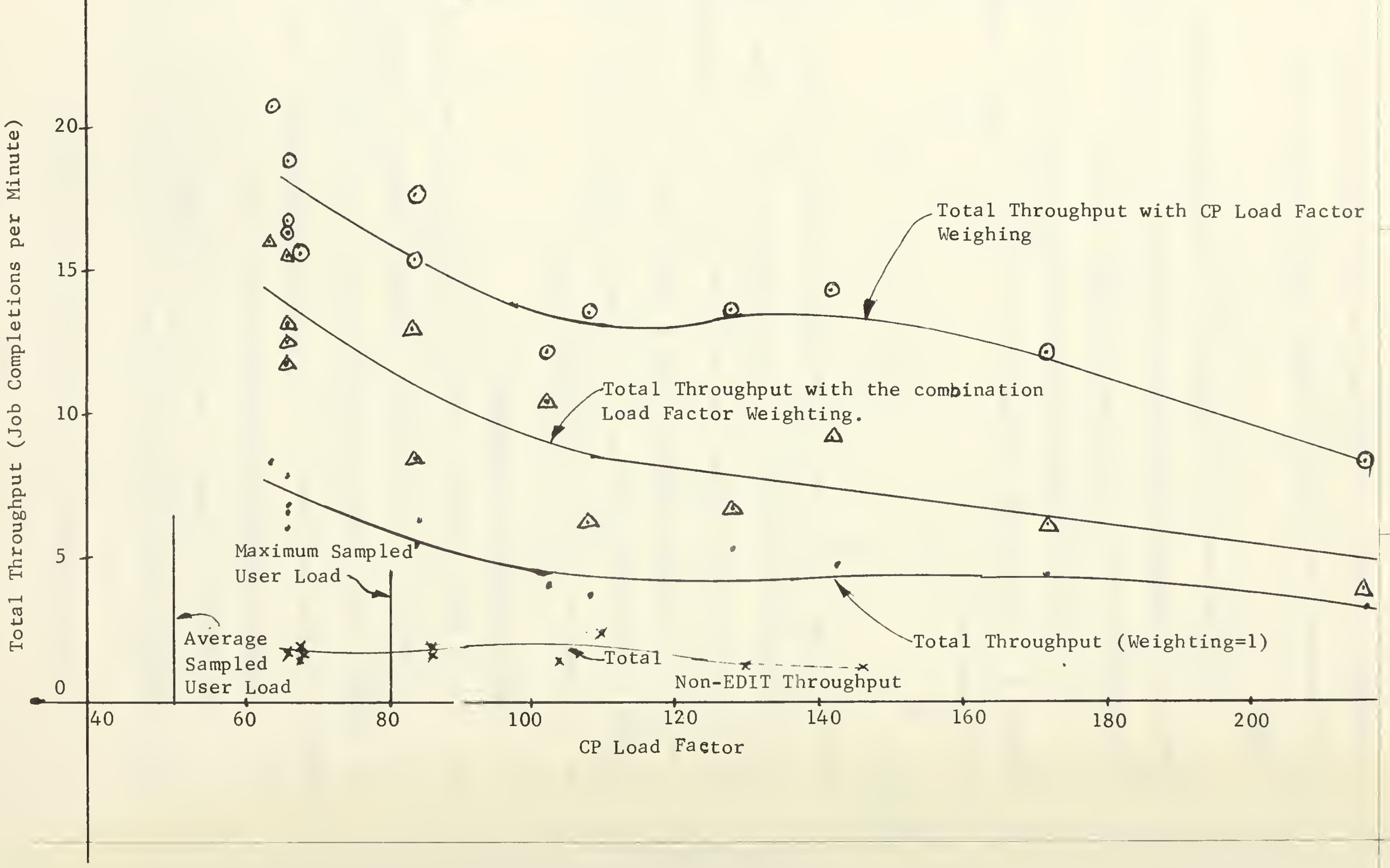


Figure 7: CP MEAN CALCULATED THROUGHPUT vs MEASURED TERMINAL THROUGHPUT-FORTEX, PLISM, PLILG

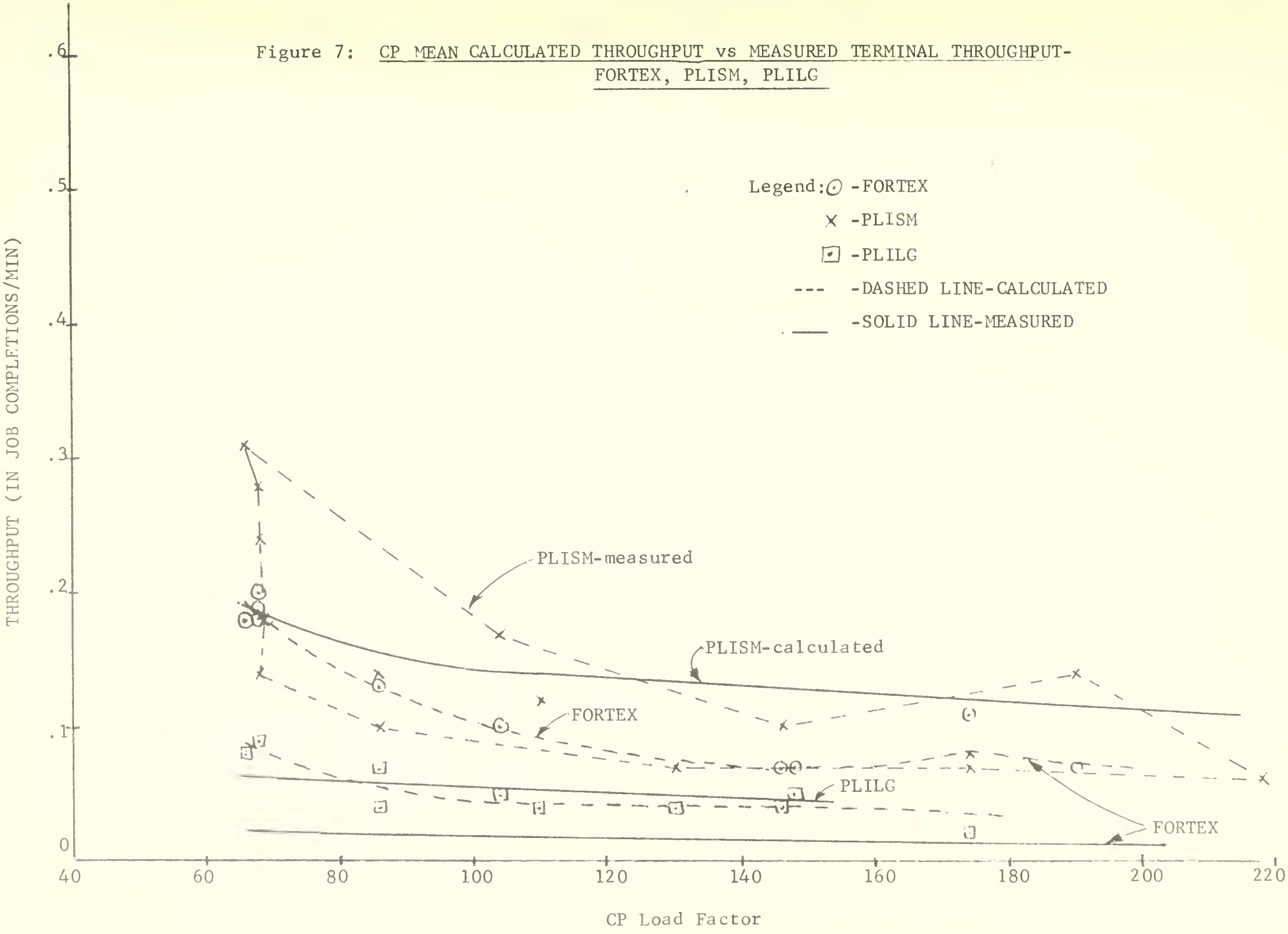
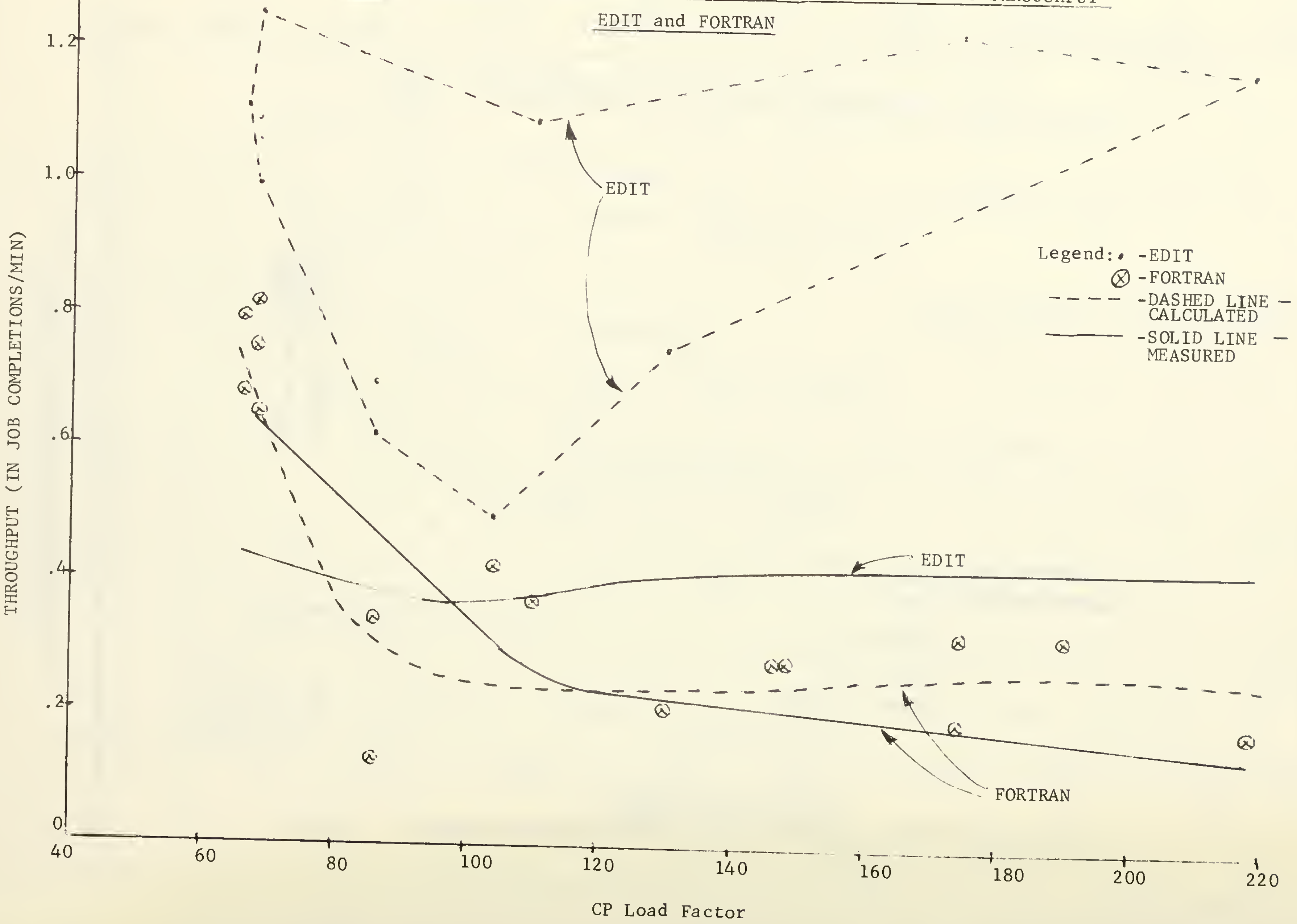


FIGURE 8. CP MEAN CALCULATED TERMINAL THROUGHPUT vs MEASURED TERMINAL THROUGHPUT-
EDIT and FORTRAN



calculated throughput. As expected the calculated throughput is generally higher than the measured throughput. This is particularly true for short-execution programs, such as EDIT and FORTEX, where a large part of the total elapsed time is involved in the overhead of running the scripts and calling the clock rather than executing the actual programs. The reasons for the calculated throughput sometimes being lower than the measured throughput is due to some errors in measurement and the fact that mean values are being plotted whereas there is often large variance in the actual data points. The actual data points from which these graphs were made are in Appendix C in Table C3.

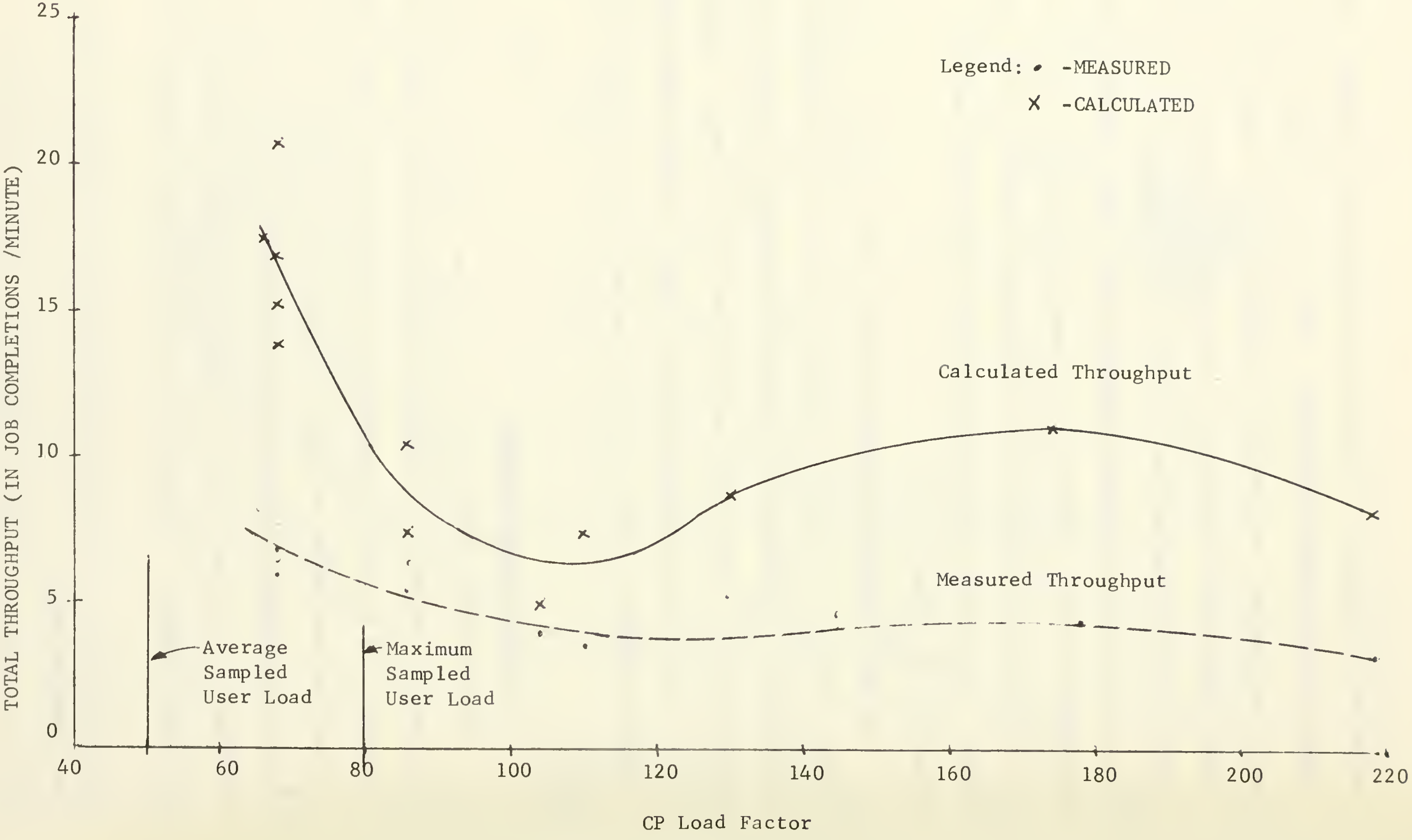
The total measured throughput and the total calculated throughput are shown in Figure 9. The points represent the sum of the throughputs for all the scripts. As expected the calculated throughput is larger than the measured values. Both curves have the same general shape - dropping quickly as the load factor increases from 68 to about 110, then rising slightly and finally falling off again as the load increases into the heavy overload region.

6.2.4 Effective Progress Rates

The effective progress rate is on another indicator of the performance of a computer system. The effective progress rate was originally defined by Lasser [15] as the time required for a program to run stand alone divided by the time required to run under the given load condition.* If the sum of effective progress rates for all programs of a particular type currently being executed is one, then the computer is operating as well as a serial processing computer. The amount over one indicates the degree to which the

*The reciprocal of the effective progress rate is sometimes referred to as the dialation factor.

Figure 9: CP TOTAL MEASURED AND CALCULATED THROUGHPUT



performance is improved by overlapping the use of various resources under multiprogramming. Effective progress rates less than one indicate the system is operating more poorly than a serial processing computer due to heavy overloading.

The effective progress rate for each script is presented in Figure 10. The most obvious observation from Figure 10 is that all the points for all scripts are grouped together. The effective progress rates for the scripts drop rapidly as the load factor increases from 40 to 90 but then remain relatively constant at between 0.02 and 0.05 as the load increases above 90.

The total effective progress rate, as presented in Figure 11, is almost constant at 0.8 for load factor from 85 to 150. This means the computer is operating at 80 percent of the throughput of a serial, one-job-at-a-time, processor. For load factors less than 85, the total effective progress rate rises rapidly to about 1.2 at 65. Unfortunately, there is not sufficient data to determine the total effective progress rate at lower load factors where the multiprogramming advantages are more noticeable.

In an attempt to predict the effective performance at lower loading conditions, some speculation was done on the probable terminal response time at the low loads. Using Figure 2, it is possible to speculate on the terminal response times for light loads such as runs R21 to R25. Assuming (1) that the response times are linear from the lower end of the curve to the zero load factor point, (2) that the response times are at their minimum (or stand-alone) values as given in Table C6 in Appendix C at zero load

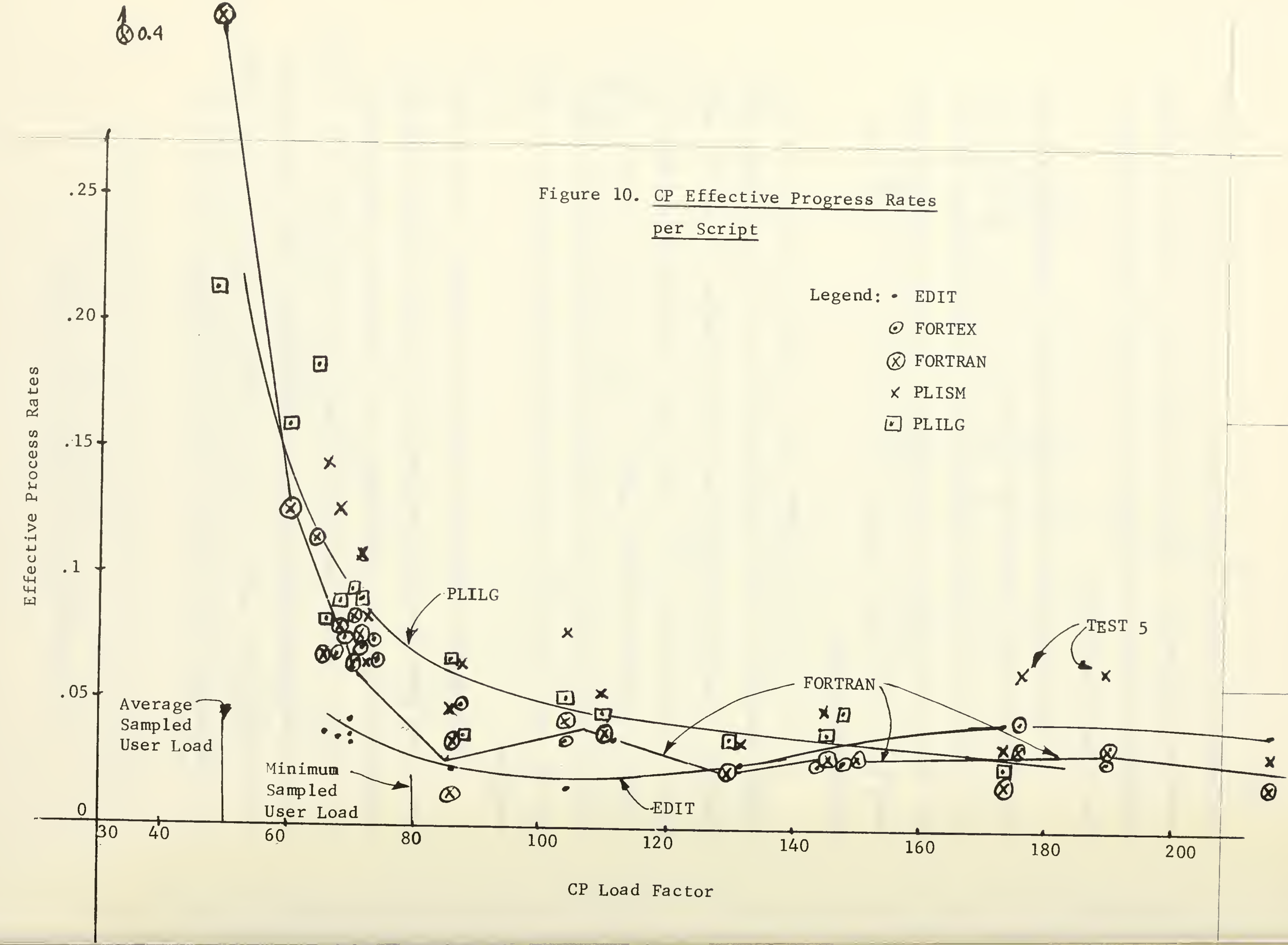


Figure 10. CP Effective Progress Rates per Script

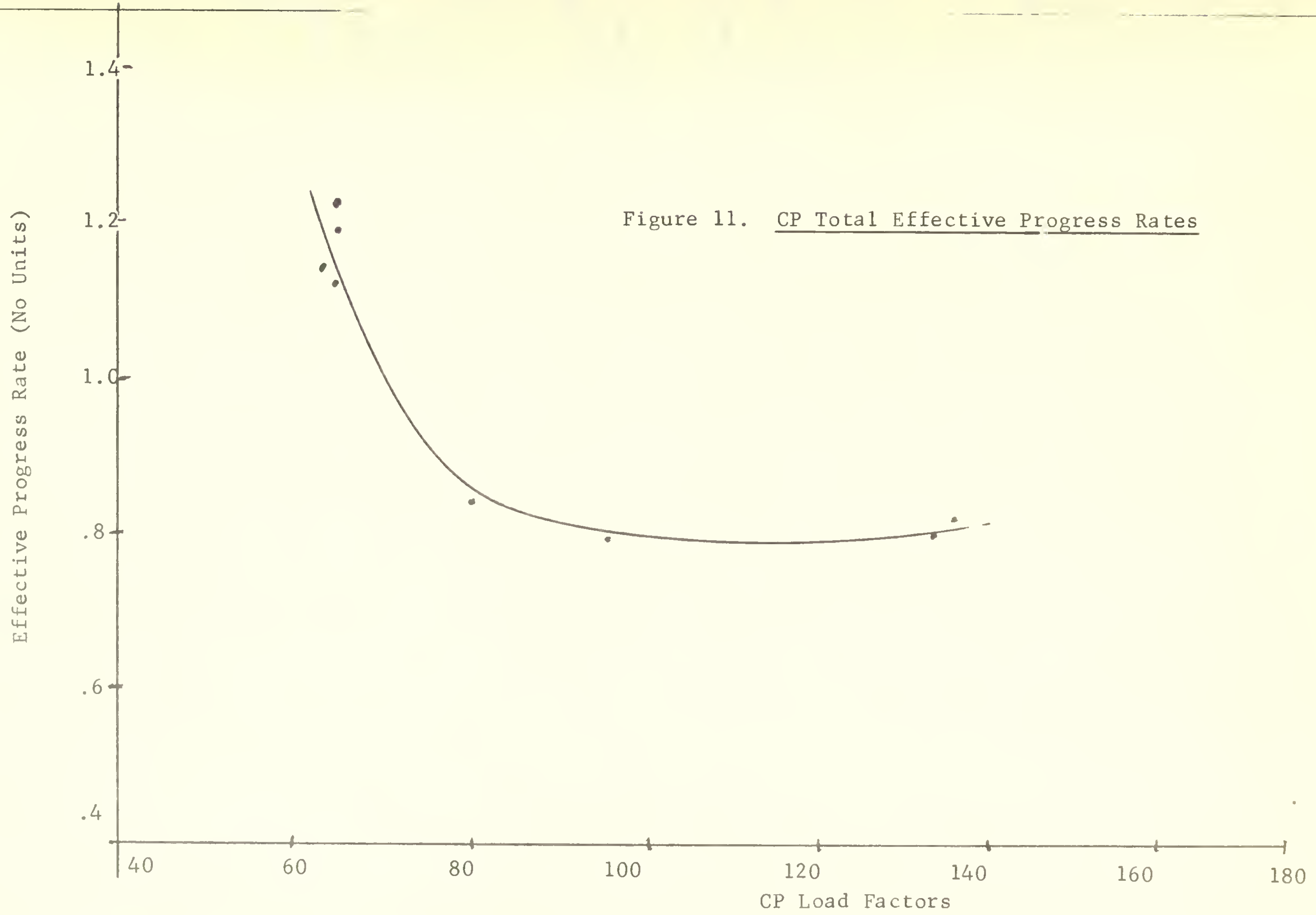


Figure 11. CP Total Effective Progress Rates

factor point, and (3) that the EDIT curve stays below the FORTRAN curve in Figure 2, then it is possible to predict (approximately) the terminal response times fro EDIT, FORTEX and PLISM scripts at low load factors. The conjectured response times for runs R21 to R25 are shown in Table 9.

The effective progress rates were then calculated from the conjectured response times and are also shown in Table 9. The conjectured effective progress rates range from 1.5 at a load factor of 64 to 3.8 at a load factor of 32. Unfortunately, these values are very dependent on the EDIT response times - since there are 8 to 15 EDIT scripts running. Therefore the EDIT response times may change the effective progress rates significantly especially for low load factor where it is difficult to predict the edit response times accurately.

Since the normal operating load factor was determined to average about 50 with peak to 80 (Section 5.4), Table 9 suggests that the CP system normally operates with a total effective progress rate of 3, but Figure 11 shows that rate may drop to as low as 0.8. In other words, during normal operation it is conjectured that the CP time sharing system processes jobs about three times as fast as it would if it operated sequentially (no multiprogramming and no overlapping of input/output and processing). However, during peak loads the CP system processes jobs at only 0.8 times as fast as it would if it processed jobs sequentially.

It seems from the above evidence that it behouves the designer of CP system to ensure that system does not accept new jobs when it is approaching, or already over, the critical load factor. This subject will be discussed further in a later section.

Table 9: Total Conjectured Effective Progress Rates - CP

Item \ Run	R21	R22	R23	R24	R25
CP Load Factor	32	32	48	60	64
EDIT response	.1	.1	.2	.5	.7
FORTEX response	1.5	1.5	2.5	3.8	4.2
PLISM response	1.5	1.5	2.5	3.8	4.2
EDIT Progress Rate	.3*	.3*	.17	.07	.05
FORTEX Progress Rate	.25	.25	.15	.1	.09
PLISM Progress Rate	.3	.3	.2	.12	.11
EDIT Progress rate times Number of EDITs	2.4*	3.0*	2.0	.98	.75
Total Conjectured Progress Rates (Also uses Table C7)	3.5*	3.8*	3.0	1.8	1.5

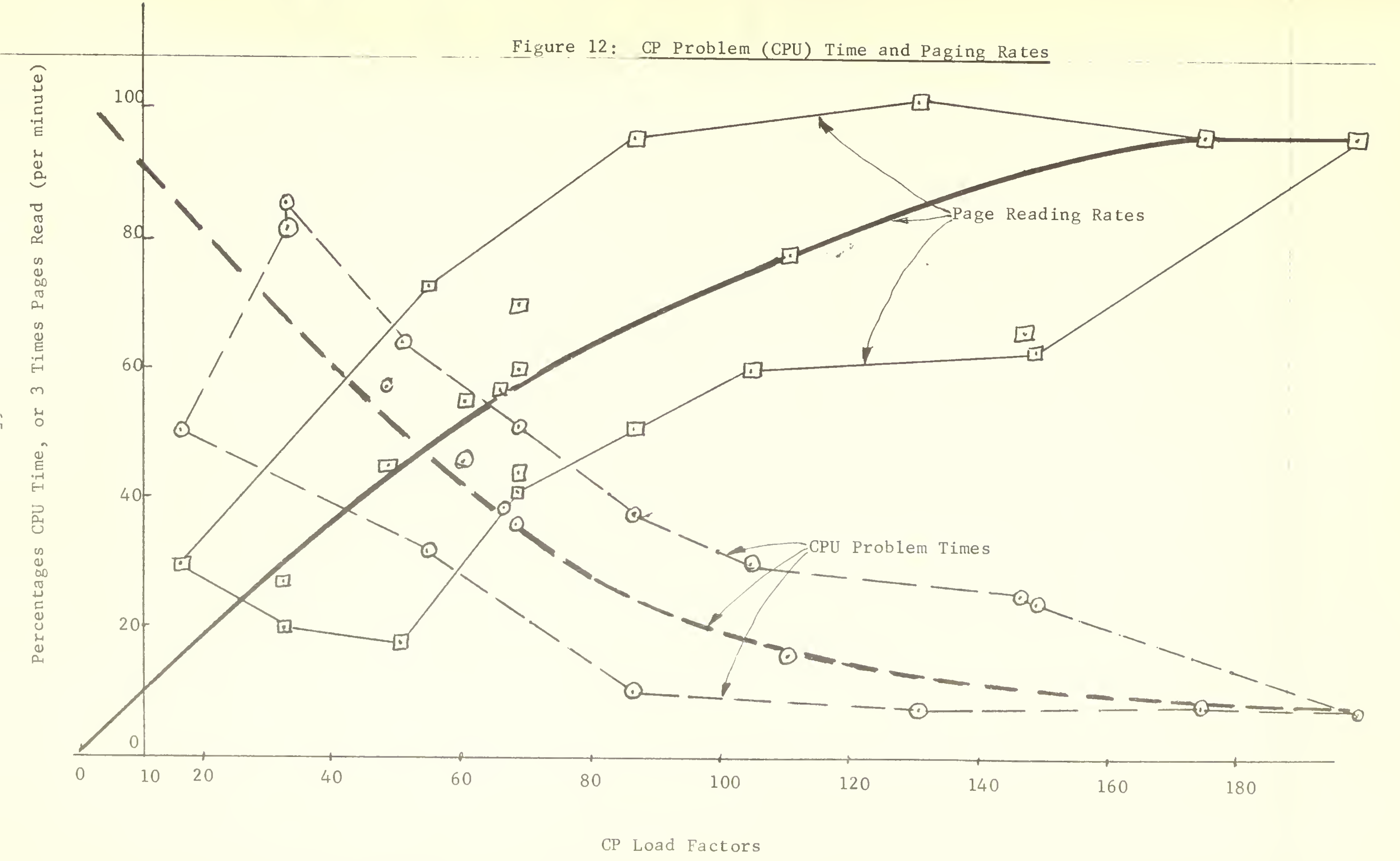
*These EDIT effective progress rate may be in error and may be as low as 0.2 or as high as 0.7. For the 0.2 value, the total conjectured effective progress rate would then be 2.7 and 2.8 for runs R21 and R22, respectively; for the 0.7 value, the total progress rate would be 6.7 and 7.8 for runs R21 and R22 respectively.

6.2.5 CP Software Monitor Results

The secondary performance measurements for determining system efficiency and performance were obtained from a CP software monitor called "MEASURE". MEASURE was obtained from Mr. Stuart Wecker of the State University of New York, Stony Brook, New York. MEASURE provided information such as: CPU problem time, supervisor time, overhead time, pages reading rate, pages swapped rate (written on back-up storage), and pages stolen rate (removed from core while the user was in one of the active queues). In addition to the system totals, each user was also monitored for the same information. MEASURE provided information at different intervals and was run continuously while the benchmark programs were under testing. From these observations the percentage of CPU time spent in problem state and the paging rates were used as indications of the load on the system.

The results of a CP software monitor are presented in Figure 12, which shows the percentage of CPU time spent in the problem state and the rate at which memory pages are read from disk storage into fast memory. There is a wide variation in both the CPU problem time and the page reading rate as a function of load factor as shown by the large envelops in Figure 12. However there is a definite trend as shown by the heavier center curves. The CPU problem percentage starts near 80 percent for a load factor of 20, drops below 50 percent for a load factor of 55 (the average user load), drops to 30 percent for a load factor of 80 (the normal maximum load) and then drops continually to 7 percent. On the other hand the pages-read rate starts at zero and increases to 35 pages per minute. The reason for the

Figure 12: CP Problem (CPU) Time and Paging Rates



rapidly decreasing CPU problem time is the heavy demand for new pages and the limited input/output channel capacity.

The relationship between the problem time and the paging rate is shown more gramatically in Figure 13 which shows that, over all the CP tests conducted, there is a consistent relationship that:

$$\begin{array}{l}\text{percentage}\\ \text{problem time}\end{array} = 100 - 3 \times \text{Paging Rate}.$$

This formula shows that to get high CPU utilization (and therefore high throughput), it is necessary to limit the paging rate rather severely.

The percentage of time that the processor spends running the operating system, commonly called overhead, is also of interest. Figure 14 shows the percentage of time that the processor spent in problem state, in problem state plus supervisor state, and in supervisor state for Test 4. Since the load increases from R42 to R46 and then abruptly decreases, the problem time percentage decreases from about 40 percent in Run R42 to about 20 percent in Run R46 due to overloading. However the percentage of supervisor time stayed approximately constant at 13 to 18 percent. The points plotted in Figure 14 are actually successive reading from the software monitor, MEASURE, rather than averages for the runs.

Figure 15 demonstrates the shift of resource allocation as the number of PLILG is increased to effectively increase the total load. The percentage of processor time allocated to FORTEX decreases as the load increases, although the number of FORTEX script was almost constant.

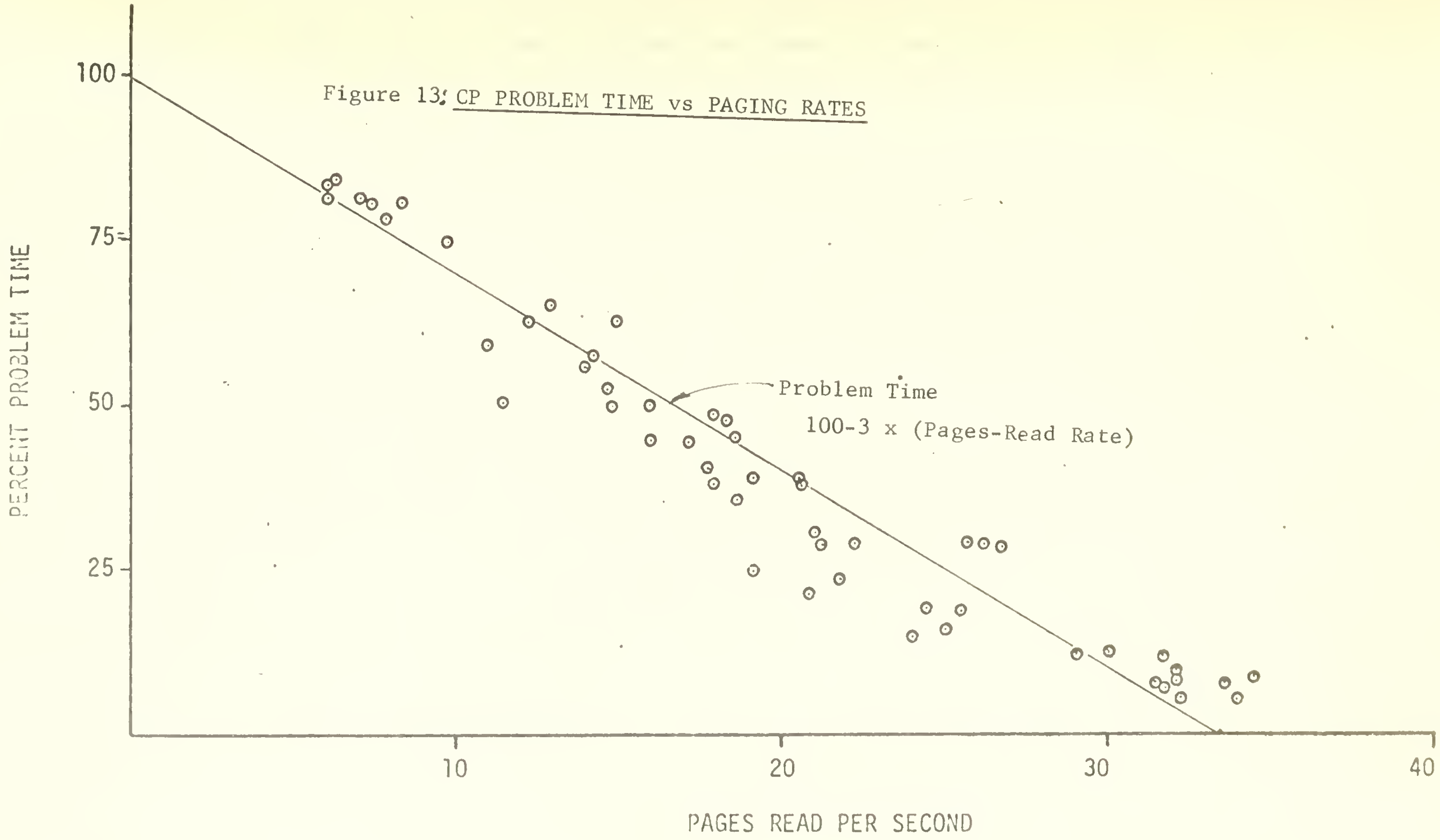


Figure 13: CP PROBLEM TIME vs PAGING RATES

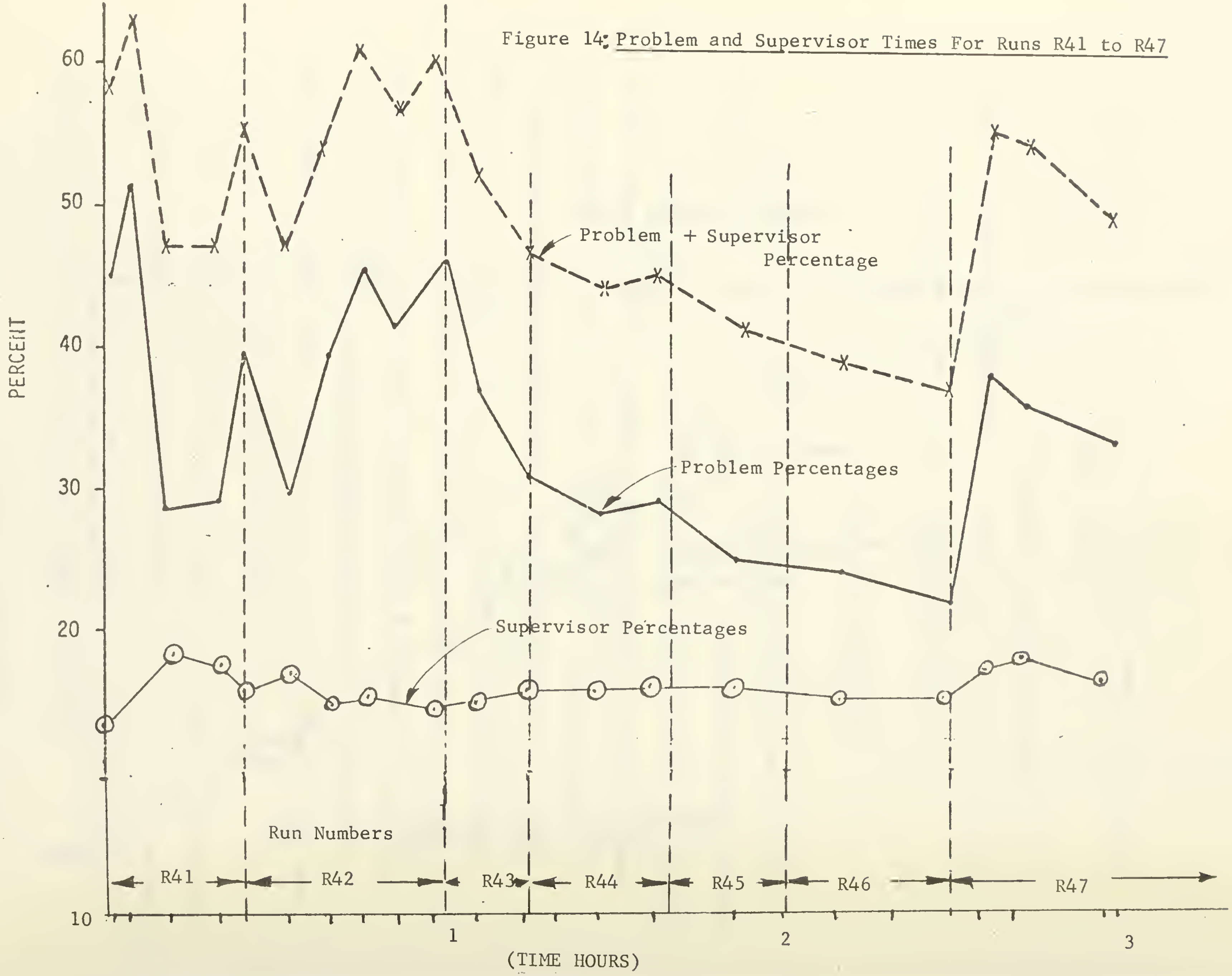


Figure 14: Problem and Supervisor Times For Runs R41 to R47

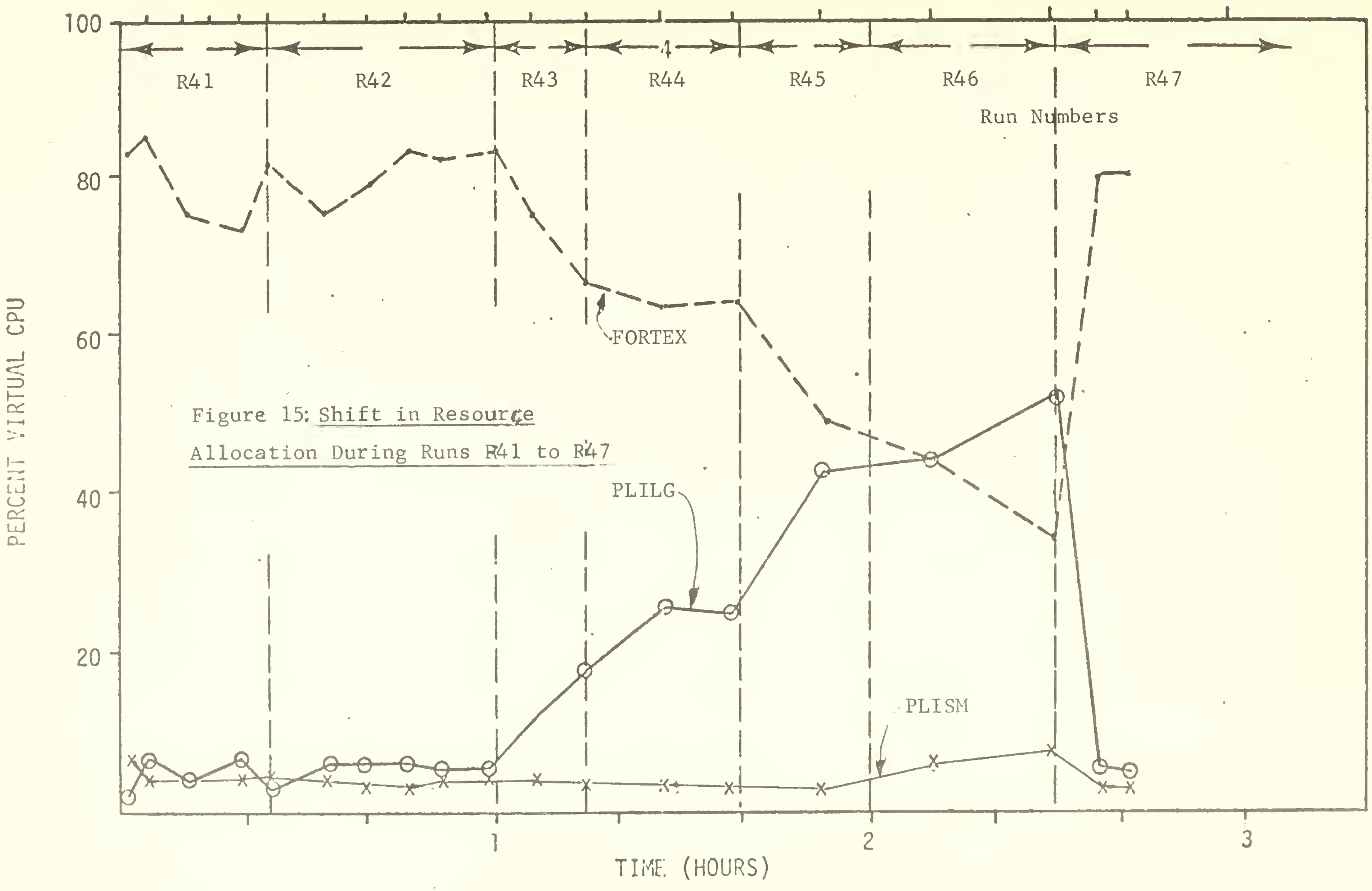


Figure 15: Shift in Resource Allocation During Runs R41 to R47

6.3 TSS Test Results

This section presents the results of 9 TSS terminal benchmarking runs under normal to heavy loading conditions. The description of the programs and scripts and the assignment of scripts to terminals during the benchmark runs were presented previously in Sections 2.2.1 and 3.1, respectively. The results in this section include the terminal response times, the measured terminal throughputs and the calculated terminal throughputs. The results are shown in graphical form with the tabular the equivalent shown in Appendix D.

6.3.1 TSS Terminal Response Times

The TSS terminal response times for various CP load factors are shown in Figure 16. The response time curves are fairly smooth functions of the CP load factor but with a definite concave-downward appearance. The PLILG curve shows the greatest degree of curvature. Since the CP load factor appears to have weights that are too large for the TSS response times, these response times were replotted against the combined load factor as shown in Figure 17. In this case, the concave-downward curves are replaced with linear curves again. This demonstrates that the combined load factor is more realistic for TSS than the CP load factor.

The PLILG response as shown is 6 minutes for the average user load, 14 minutes for the heaviest sampled user load and 25 minutes for the heaviest benchmarking load. The corresponding figures for FORTRAN are 1 minute, 2 minutes and 4-1/2 minutes, respectively. The response times for PLISM are only slightly less than for PLILG. Unfortunately the results

Figure 16: TSS Terminal Response Times for various CP Load Factors

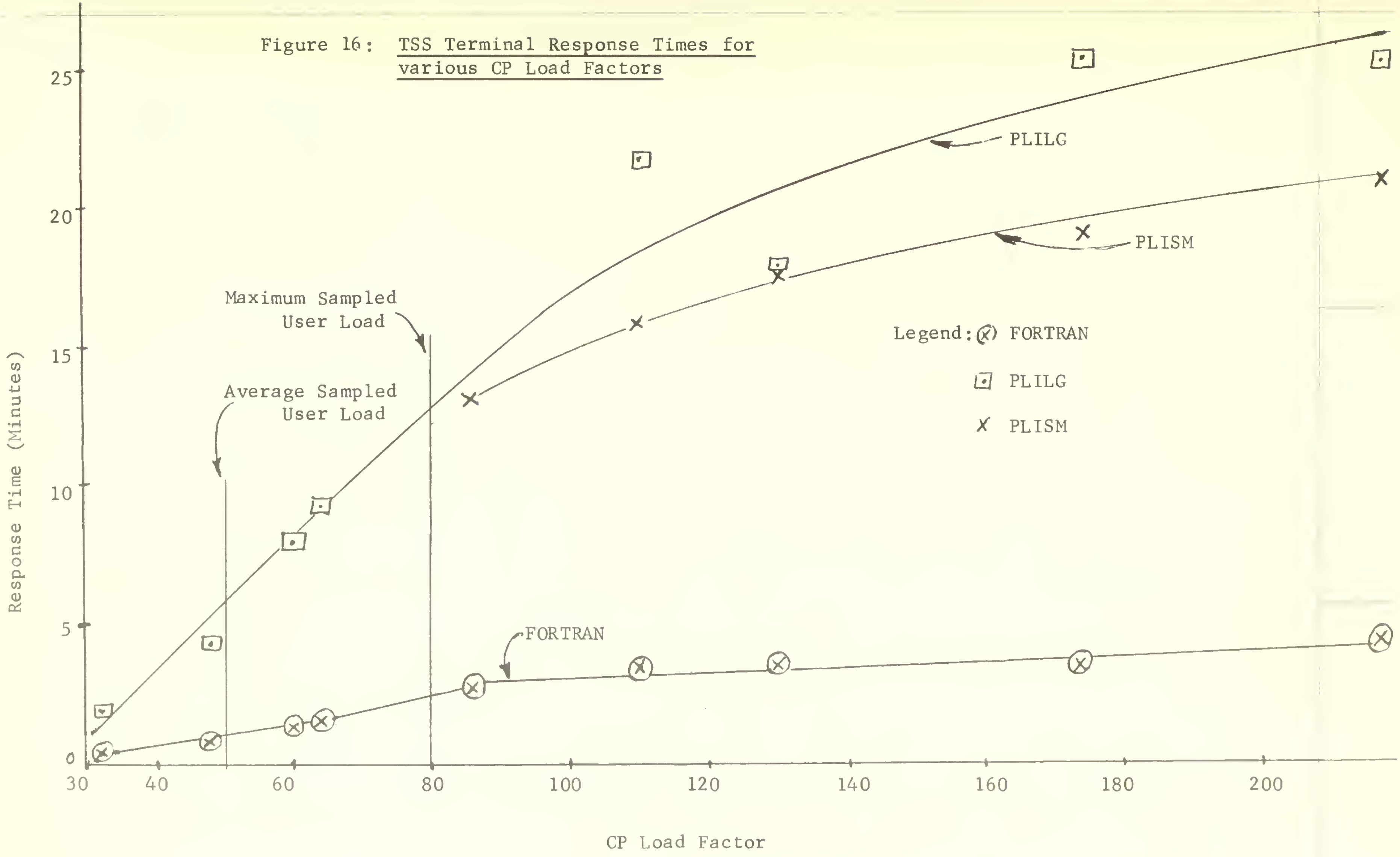
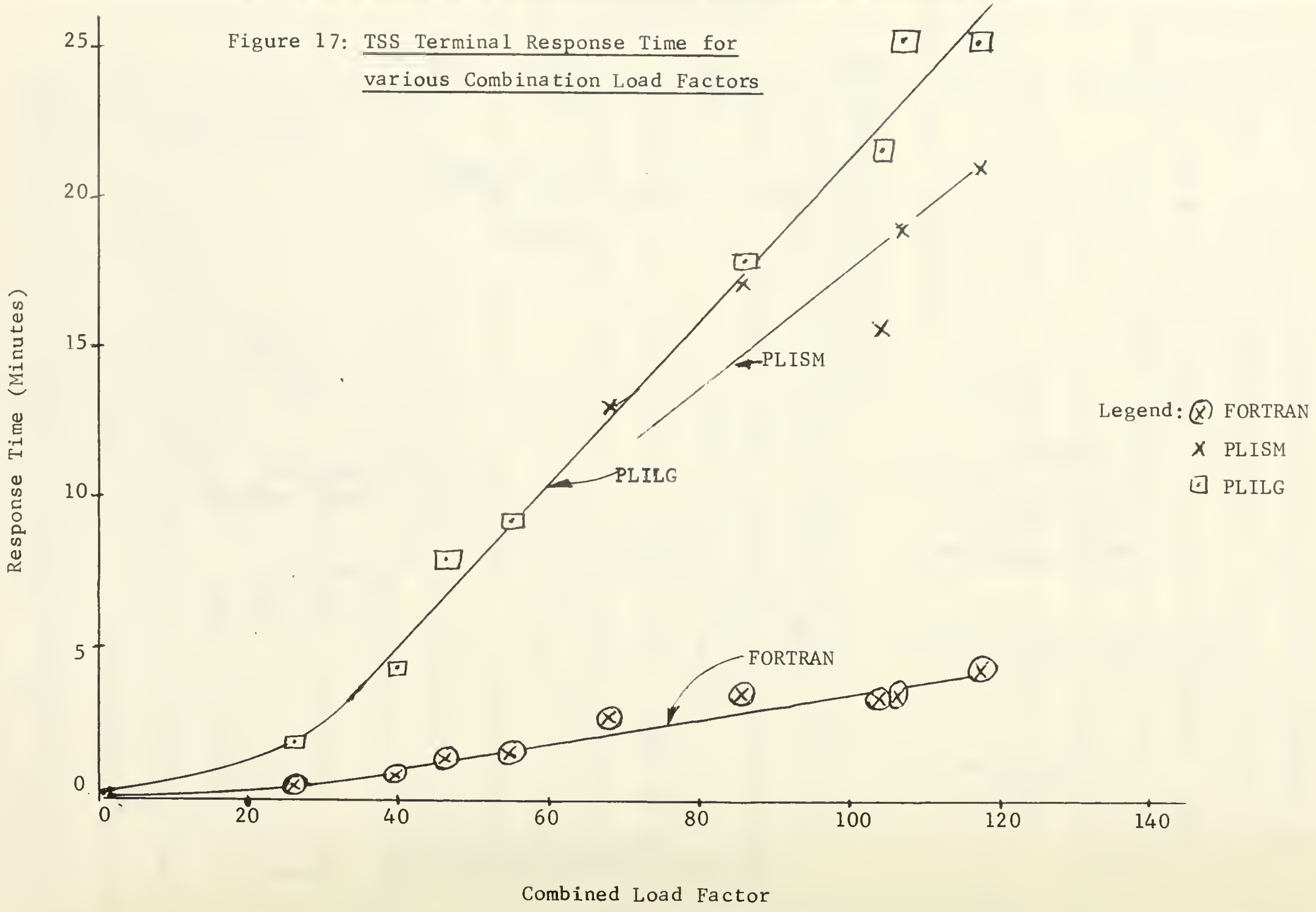


Figure 17: TSS Terminal Response Time for various Combination Load Factors



from the EDIT and FORTEX scripts were not available from the TSS runs.

6.3.2 TSS Throughputs

The TSS measured and calculated terminal throughputs for the FORTRAN and PLILG scripts are shown in Figure 18. For very light loads (load factor = 30), the TSS throughputs for FORTRAN scripts was 3 per minute, but this quickly dropped to less than 0.5 per minute as the load approached 60. The PLILG response times started at 0.5 per minute and dropped to 0.1 per minute at the load factor of 60. There is very little difference between the measured and the calculated throughputs.

The total measured and calculated throughputs per script are shown in Figure 19. The plotted points were obtained by adding the throughputs for all terminals running the particular script. The points show the same general trend as in Figure 18, except the total is higher and the dropping is less rapid. The FORTRAN points are deceptively close to the curves, because most of the runs were made with the same number of FORTRAN scripts.

The total measured and calculated throughput is not shown because no data is available for the EDIT and FORTEX scripts. A portion of the total throughput will be presented later in Figure 24 as a comparison with CP. Also the effective progress rates are not shown because the data on the TSS stand-alone response time was not available.

6.4 CP and TSS Performance Comparisons

6.4.1 Terminal Response Time Comparisons

The performance comparison of CP and TSS over a wide range of terminal

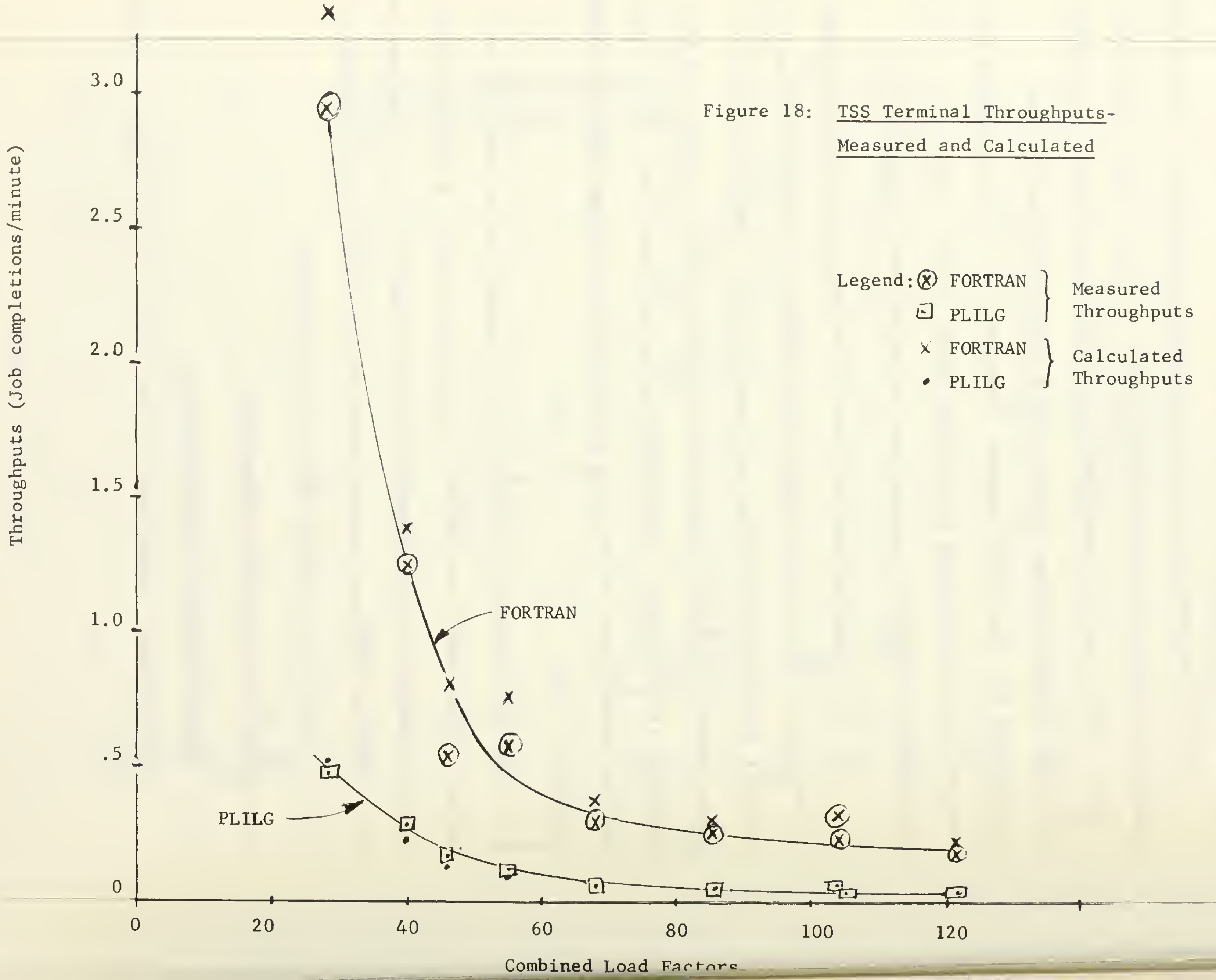


Figure 18: TSS Terminal Throughputs-Measured and Calculated

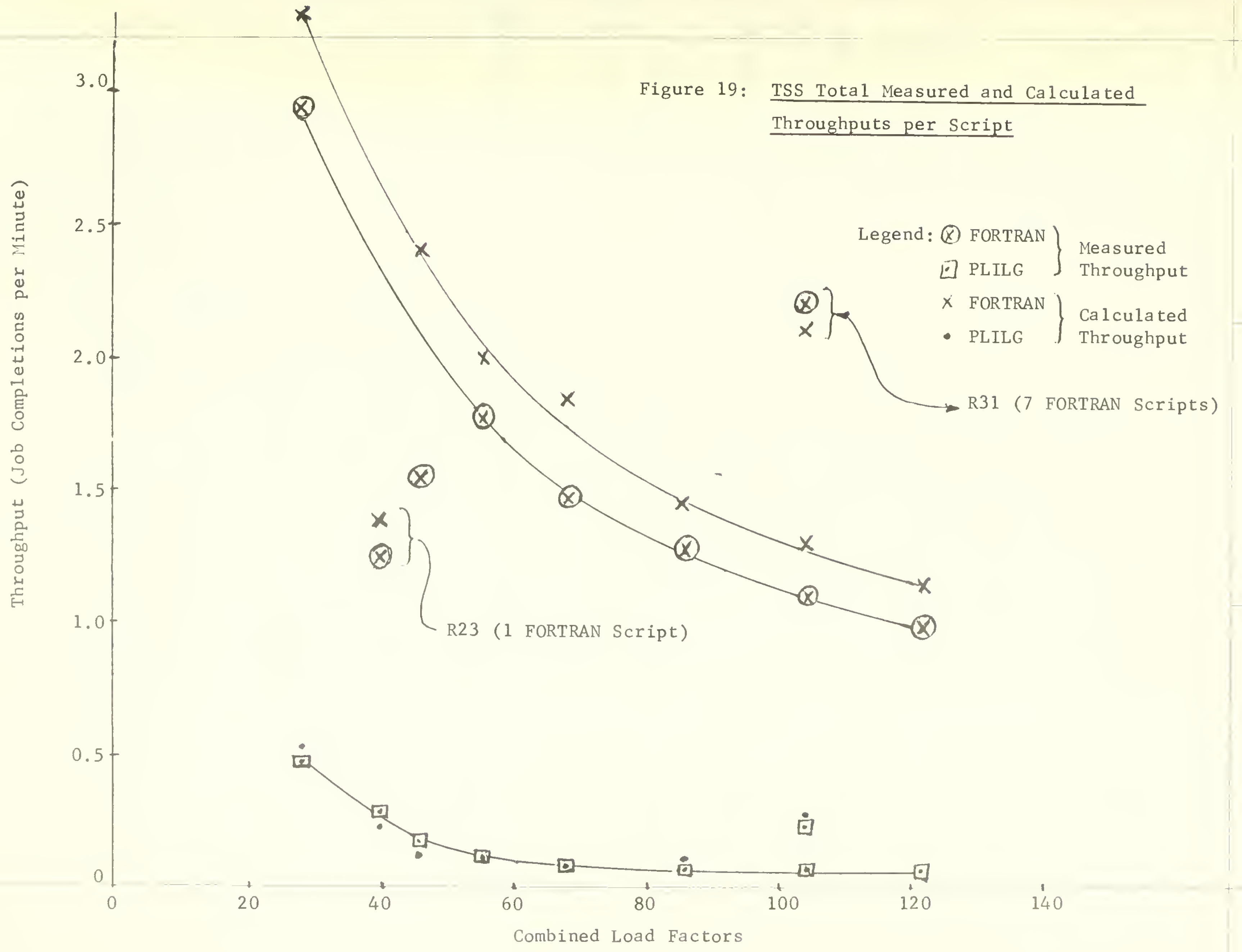


Figure 19: TSS Total Measured and Calculated Throughputs per Script

loading conditions was of primary importance in this project. Since it was necessary to use a common load indicator in order to compare CP and TSS, the CP terminal response times were replotted against the combined load factor as shown in Figure 20. When Figure 20 is compared to Figure 2, which is the same data except plotted against the CP load factor, it is obvious that there is a much wider spread in the response times in Figure 20, especially for PLILG at high loads.

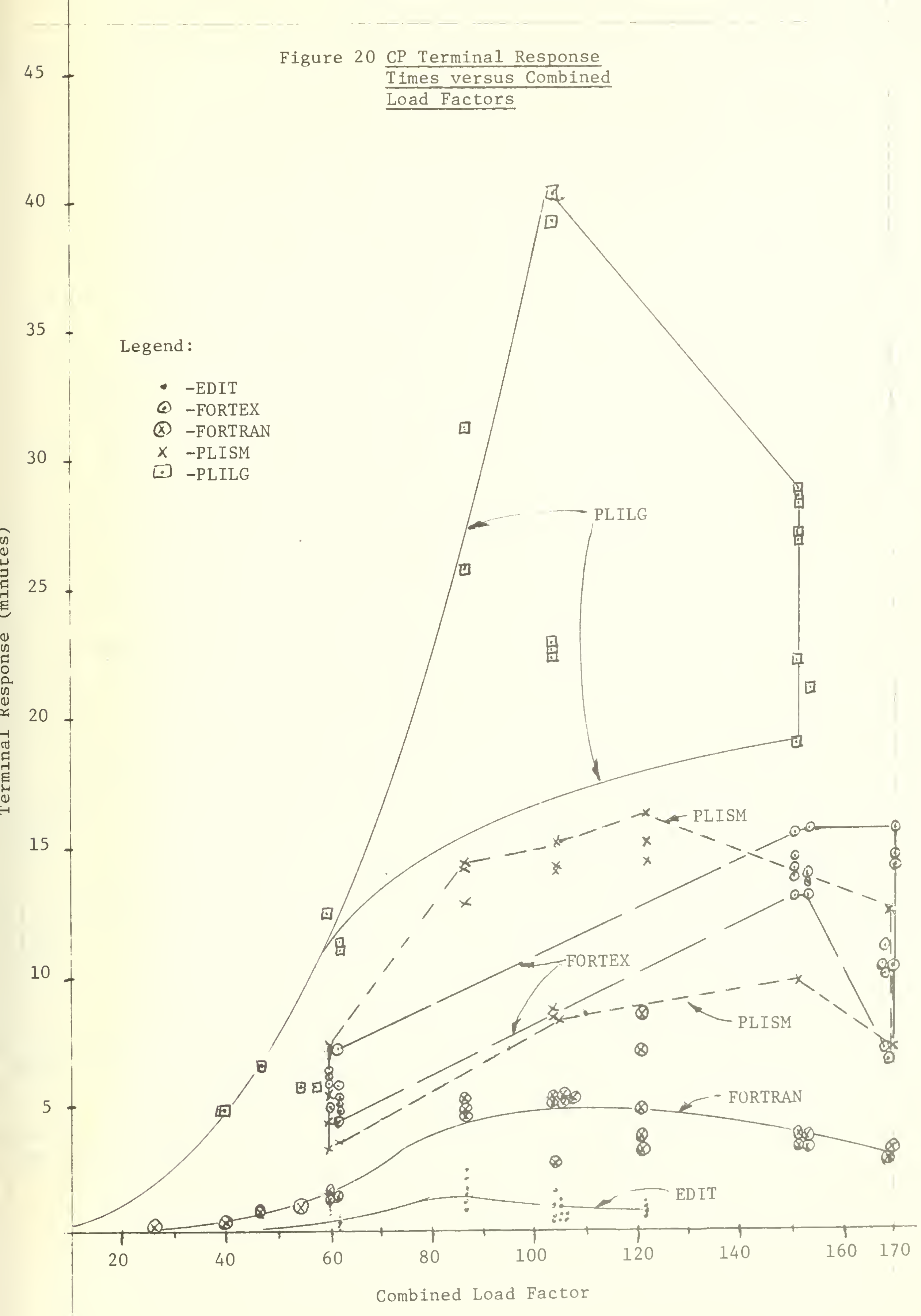
A comparison of the CP and TSS response times is shown in Figure 21, which is a combination of the CP response curves from Figure 20 and the TSS response curves from Figure 17. The PLILG and FORTRAN response times are about the same for CP and TSS, except that the CP PLILG responses have a lot more variation than the TSS equivalents at high loads. For example, at a combined load of 120 the CP response times may vary anywhere from 18 minutes to over 40 minutes, compared to a relatively predictable 26 minutes for TSS. On the other hand, the PLISM responses for CP are all much less than those for TSS.

HOWEVER, the comparison above is for two very different configurations as shown in Table 10.

Table 10: CP versus TSS Comparison Configurations

TSS	CP
Dual processor	Single processor
768K bytes memory 3 core boxes	256K bytes memory 1 core box
1 Drum	1 Drum
2314 Disk (fast)	2311 Disk (slow)

Figure 20 CP Terminal Response Times versus Combined Load Factors



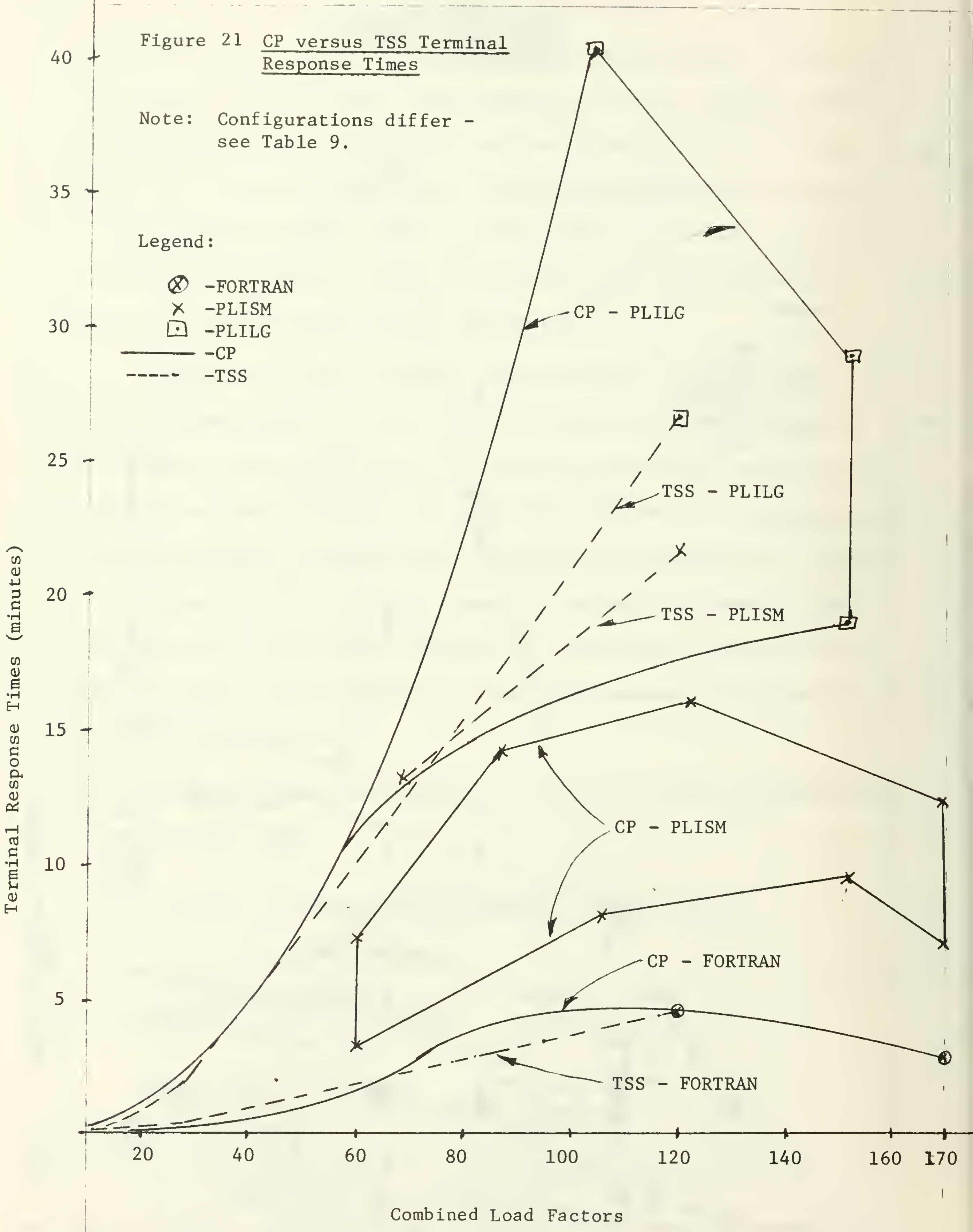


Figure 21 CP versus TSS Terminal Response Times

Note: Configurations differ - see Table 9.

Thus CP has only one third as much memory as TSS; and also it has only a single processor and slower disk units. In time sharing operations, where memory is usually the critical resource, the differences in the configurations is very significant and places CP at a serious disadvantage. Yet CP's performance is competitive.

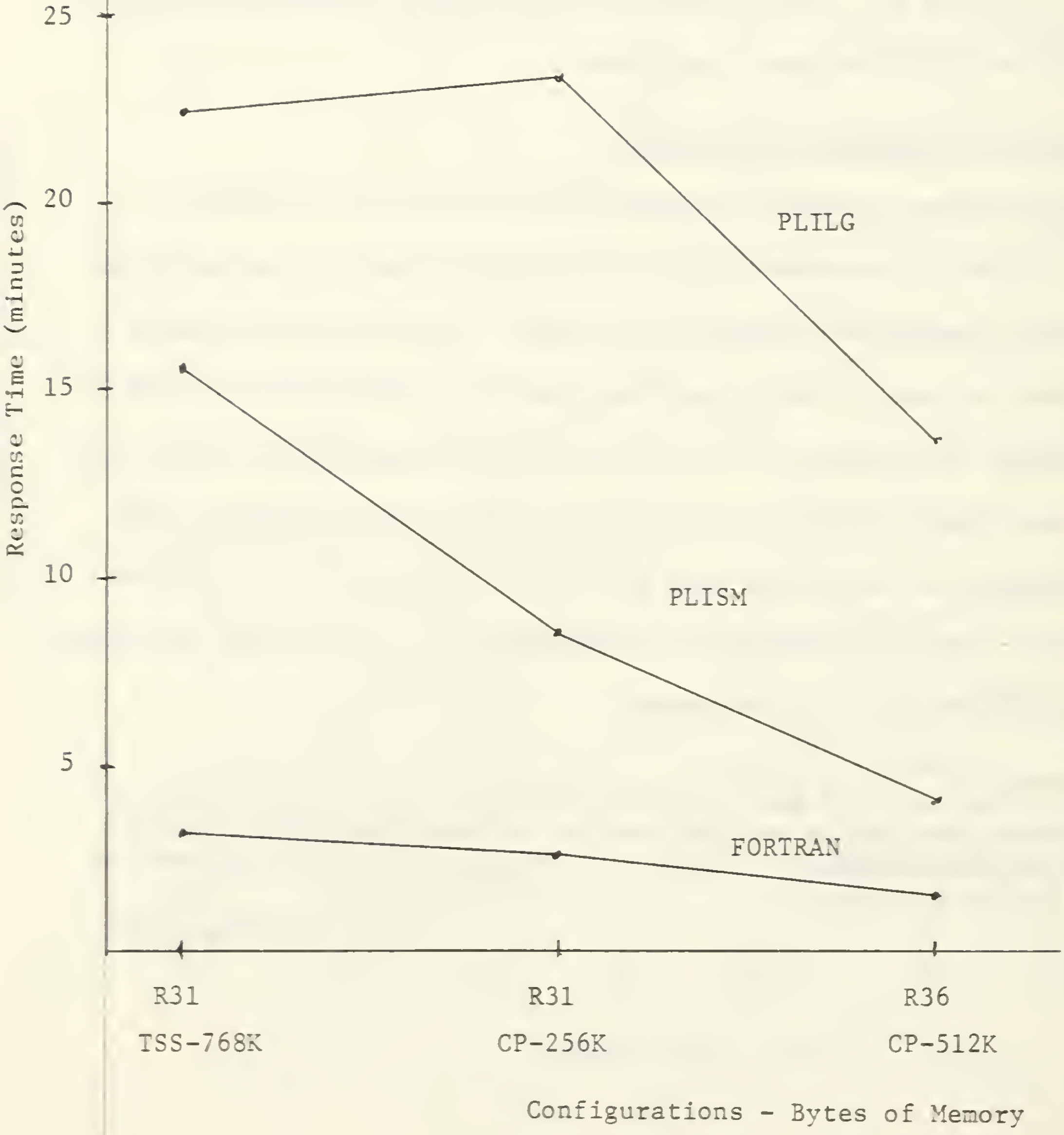
In order to determine the amount of performance improvement with extra memory, run R31 was repeated as run R36 with the same benchmark but with the two core boxes (512K bytes) configuration. The results showed that CP response times were reduced in half with the extra memory as shown in Figure 22. Thus CP with two core boxes provided twice the performance as TSS with three core boxes*.

6.4.2 Terminal Throughput Comparisons

The calculated terminal throughputs for CP and TSS are shown in Figure 23. The CP throughput data is a replot of that in Figures 7 and 8 but against the combined load factor rather than the CP load factor. The TSS data is simply the curves from Figure 18. The curves show that the CP FORTRAN throughput is better than the TSS equivalent for all load factors less than 70 and about the same for higher load factors. The PLILG throughput is about the same for CP and TSS for all load factors. The measured terminal throughput is essentially the same as the calculated throughput and thus is not presented.

*Acutally a test with CP and 3 core boxes was attempted but it had to be terminated prematurely and the results are not considered reliable enough to be included here. However, intermediate results are reported in Table C10 in Appendix C.

Figure 22 CP versus TSS Terminal Response Times for Three Configurations



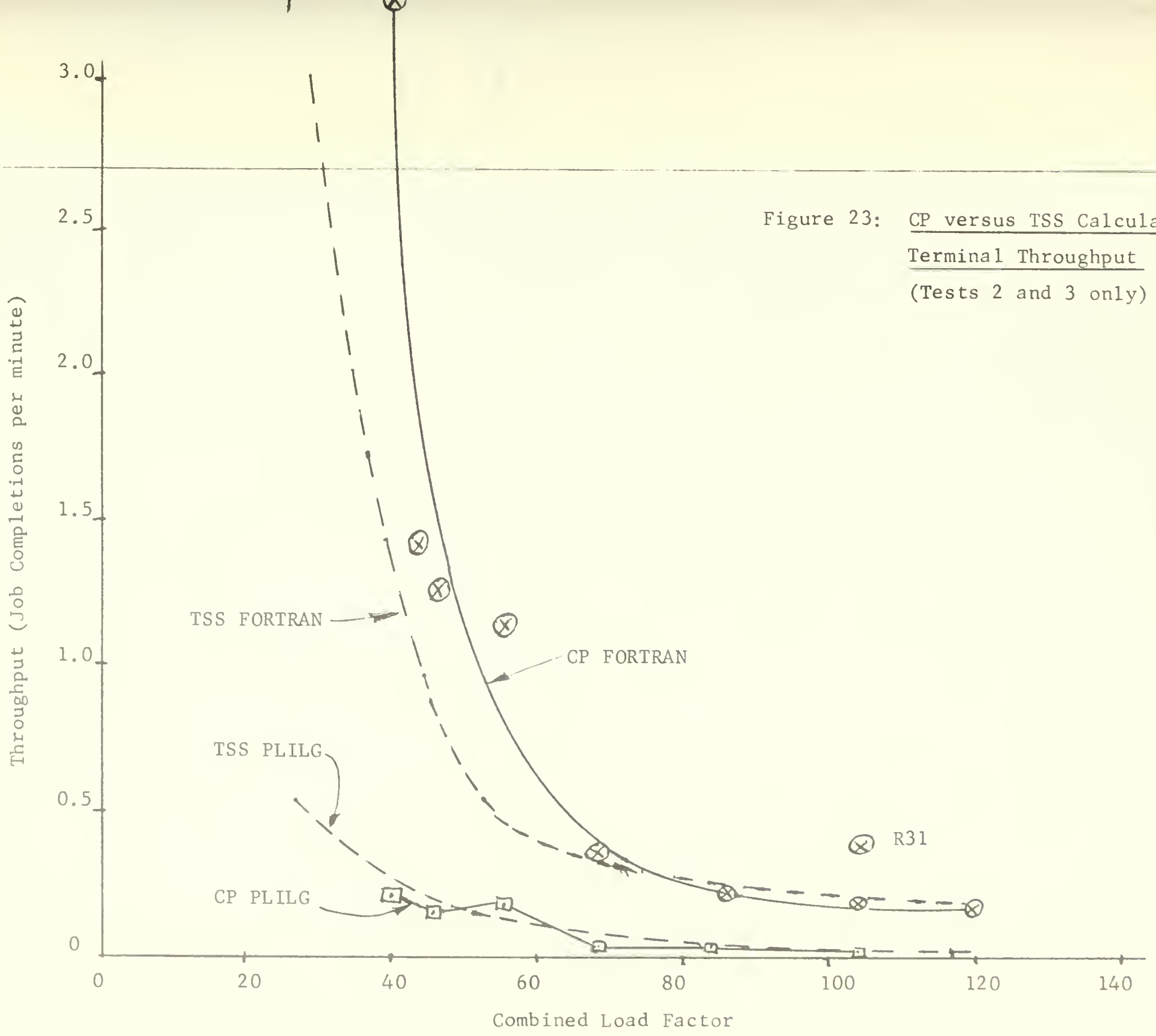


Figure 23: CP versus TSS Calculated Terminal Throughput (Tests 2 and 3 only)

Again this shows CP performance is comparable to TSS despite the large discrepancy in resourses available (as shown in Table 9).

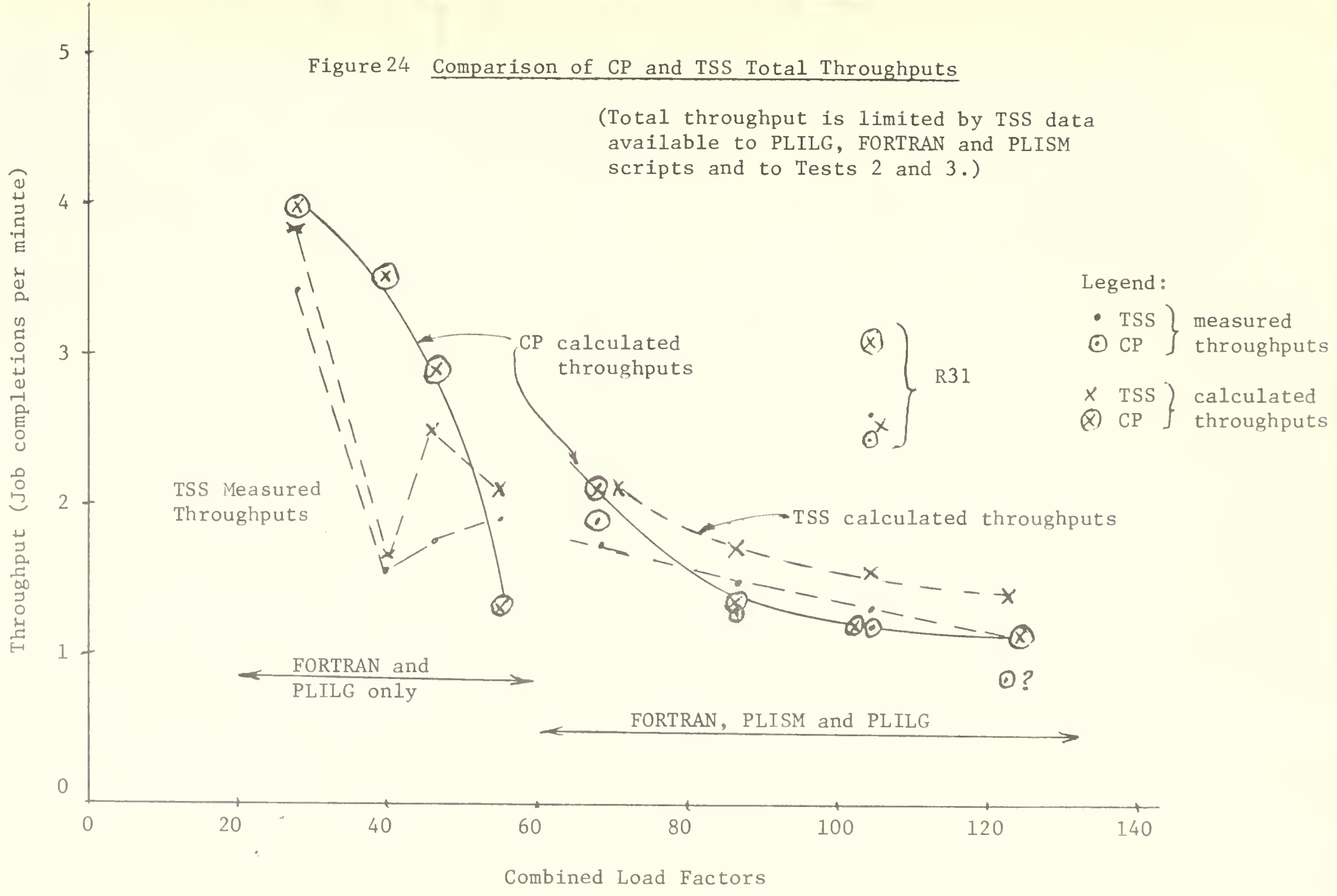
The total throughput for CP and TSS are compared in Figure 24. Since there was only limited throughput data available for TSS, only FORTRAN plus PLILG throughput is shown for Runs R21 to R25 (load factors of 28 to 55), while PLISM throughput is also included in Runs R31 to R35 (load factors above 60). Both calculated and measured throughputs are shown in Figure 24.

Again CP does very well in the comparison of total throughput. Comparing the calculated total throughput, CP has higher throughputs at low load factors and only slightly lower throughputs at the higher load factors.

This completes the comparison of CP and TSS, except for some comparison of all three terminal systems later in Section 6.7. Unfortunately, the effective progress rates for TSS could not be obtained because the stand-alone response times were not available, and therefore no comparisons were possible. Also there were no software monitor measurements for TSS for comparison with the CP data.

Figure 24 Comparison of CP and TSS Total Throughputs

(Total throughput is limited by TSS data available to PLILG, FORTRAN and PLISM scripts and to Tests 2 and 3.)



6.5 MTS Test Results

This section presents the results of 7 MTS runs, which span the range of load used for the CP benchmarking runs. The scripts and programs were the same as described previously. (The listings are also in Appendix A.) The MTS runs were made with the full 3 corebox, dual processor configuration described in Section 1.3.

6.5.1 MTS Terminal Response Times

The MTS terminal response times, as shown in Figure 25, indicate the same general response as experienced in the previous tests. The PLILG responses are the highest, with FORTEX, PLISM and EDIT are next and all about the same, and FORTRAN response times are the lowest. All the response times rise rather slowly as the load increases. For example, the PLILG response times rise from 3 minutes at a MTS load factor of 60 to 7 minutes at a load factor of 130. Suddenly, at a load factor of 130, the response time jumps to 38 minutes. An attempt to explain this peculiarity will be made later in this section.

The only other peculiarity in the above graph is that the EDIT response times seem to be much too high. Actually this is the result of the design of the MTS EDIT script and the operation of the MTS editor. The MTS EDIT script was designed to print an extra ten lines as a means of simulating the one minute delay between editor calls. Also the MTS editor prints every line that it references and thus MTS printed 9 lines (not counting the 10 above) compared to 1-1/2 lines for CP. Therefore, the MTS EDIT response times are almost 2 minutes longer than those experienced in the previous tests.

In an attempt to explain the large jump in PLILG and PLISM response times at a load factor of 130, the following analysis was made. First it should be noted that this jump in PLILG response times from 7 to 38 minutes occurred during a single benchmark test, Run R63. Since it was observed during the test that a terminal executed one PLILG or PLISM script quite rapidly and then took "forever" to complete the second execution, it was decided to plot all the response times for Run R63 as a function of the time of day, as shown in Figure E1 of Appendix E. From this plot, it was confirmed that the response times for the first few minutes of Run R63 were much lower than for the remainder of the run. Thus it was decided to break Run R63 into two runs R63a and R63b, with R63a representing the first few minutes and R63b representing the rest of Run R63.

The response times for Runs R63a and R63b are summarized in Table 11. It can be seen that there is amazing consistency between the response times within the newly defined Runs R63a and R63b, but a lot of difference between the response times.

It is almost as if MTS had labelled some jobs as trouble makers and put them on the back of a long queue, which it never got around to serving. Even an explanation of the priveleged and unpriveleged tasks will not account for this large disparity.

In order to compare MTS results with those from other systems, the MTS terminal response times were also plotted against the combined load factors as shown in Figure 26. The response time curves in Figure 26 are quite similar to those in Figure 25.

Table 11 <u>Breakdown of Terminal Response Times for Run R63</u>

	PLILG		PLISM	
Run	R63a	R63b	R63a	R63b
Terminal Response Times	8.0	37	3.5	11.7
	8.0	34.5	2.94	10.0
	7.3	28.3		11.5
	12.0			
	8.6	37.22		
	6.7	37.1		
	8.0	36.9		
	9.8	34.0		
Mean	8.55	35.0	3.22	11.1
Variance	19.36	63.09	.156	1.73
Standard Deviation	4.4	7.94	.396	1.31

Figure 25 MTS Response Time for Various Loads

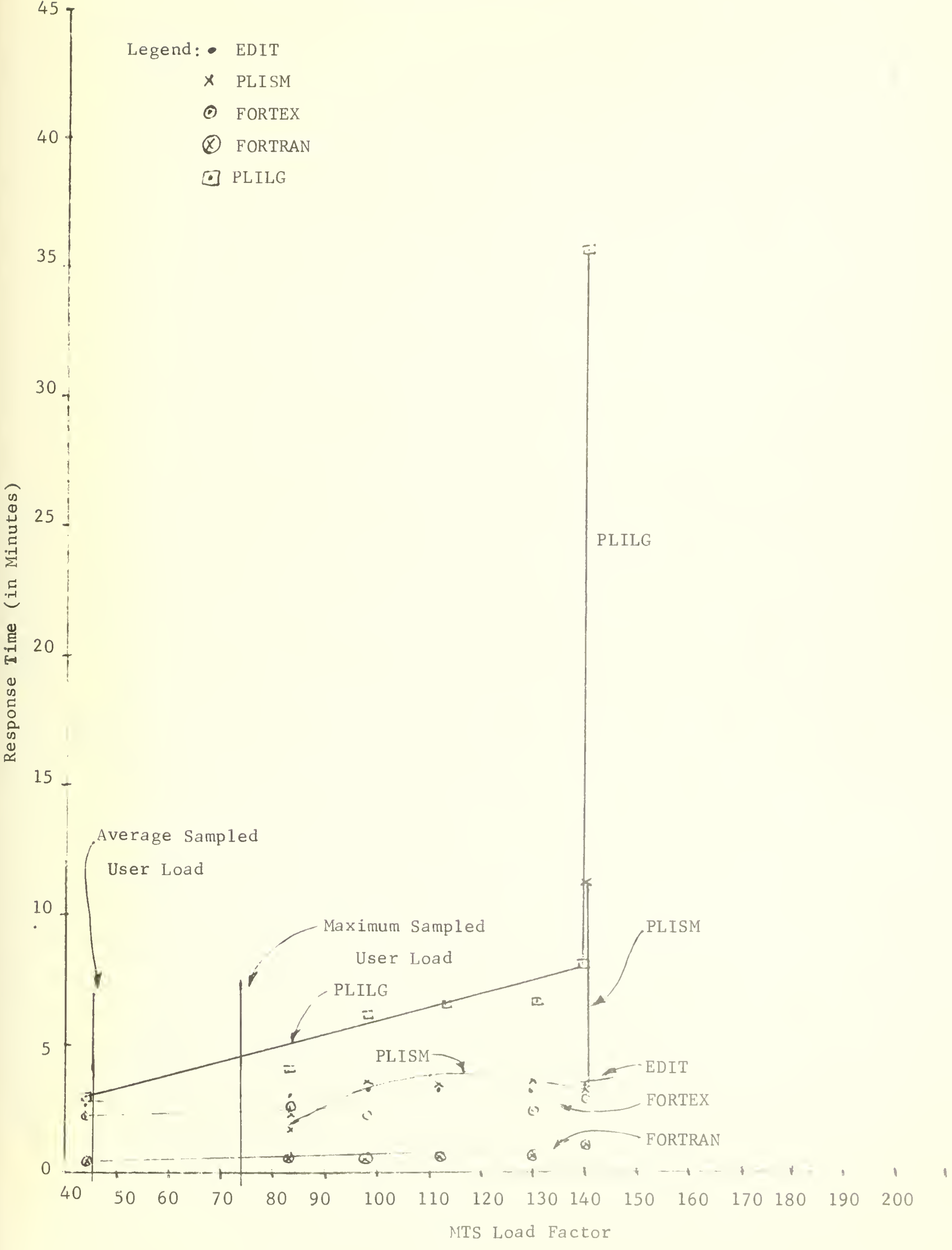
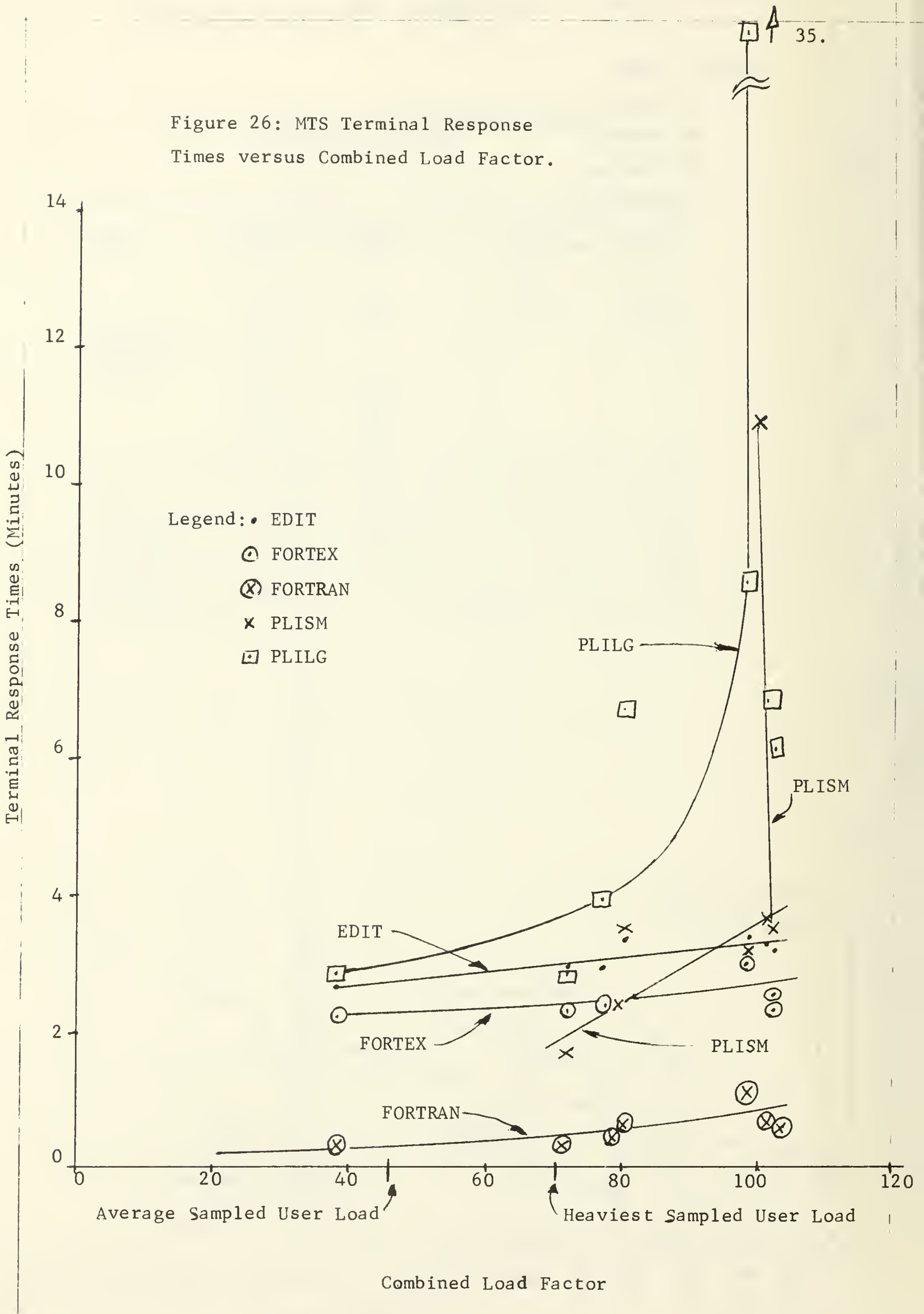


Figure 26: MTS Terminal Response Times versus Combined Load Factor.



6.5.2 MTS Throughputs

The MTS measured terminal throughputs for various MTS load factors are shown in Figure 27. The FORTRAN measured throughput curve has quite a strange shape - almost a saw-toothed shape. It starts at 0.6 job completions per minute at a load factor of 40, increases to 1.8 jobs per minute at 100 and then drops to 0.4 job completions per minute at a load factor of 140. The other measured throughputs are all much less than the FORTRAN throughputs and therefore are replotted on an expanded scale on Figure 27b.

The PLILG measured throughputs drop the most rapidly from 0.3 job completions per minute at a load factor of 40 to 0.03 job completions per minute at a load factor of 140. The PLISM throughputs have a corresponding drop, but the EDIT and FORTEX scripts have a relatively small decrease in throughput as the load increases.

The total measured throughput for all terminal running a particular script is shown in Figure 28. Throughputs for PLISM, PLILG and FORTEX scripts are shown in Figure 28a while those for FORTRAN and EDIT scripts are shown on a larger scale in Figure 28b. As seen previously during the CP test results, the total throughputs per script varies radically as the resource allocation is shifted by the various benchmarks. For specific values or range of values for the throughput see Figures 28a and 28b.

The calculated throughputs for MTS are not presented here because of their similarity with the measured throughputs. This observation is

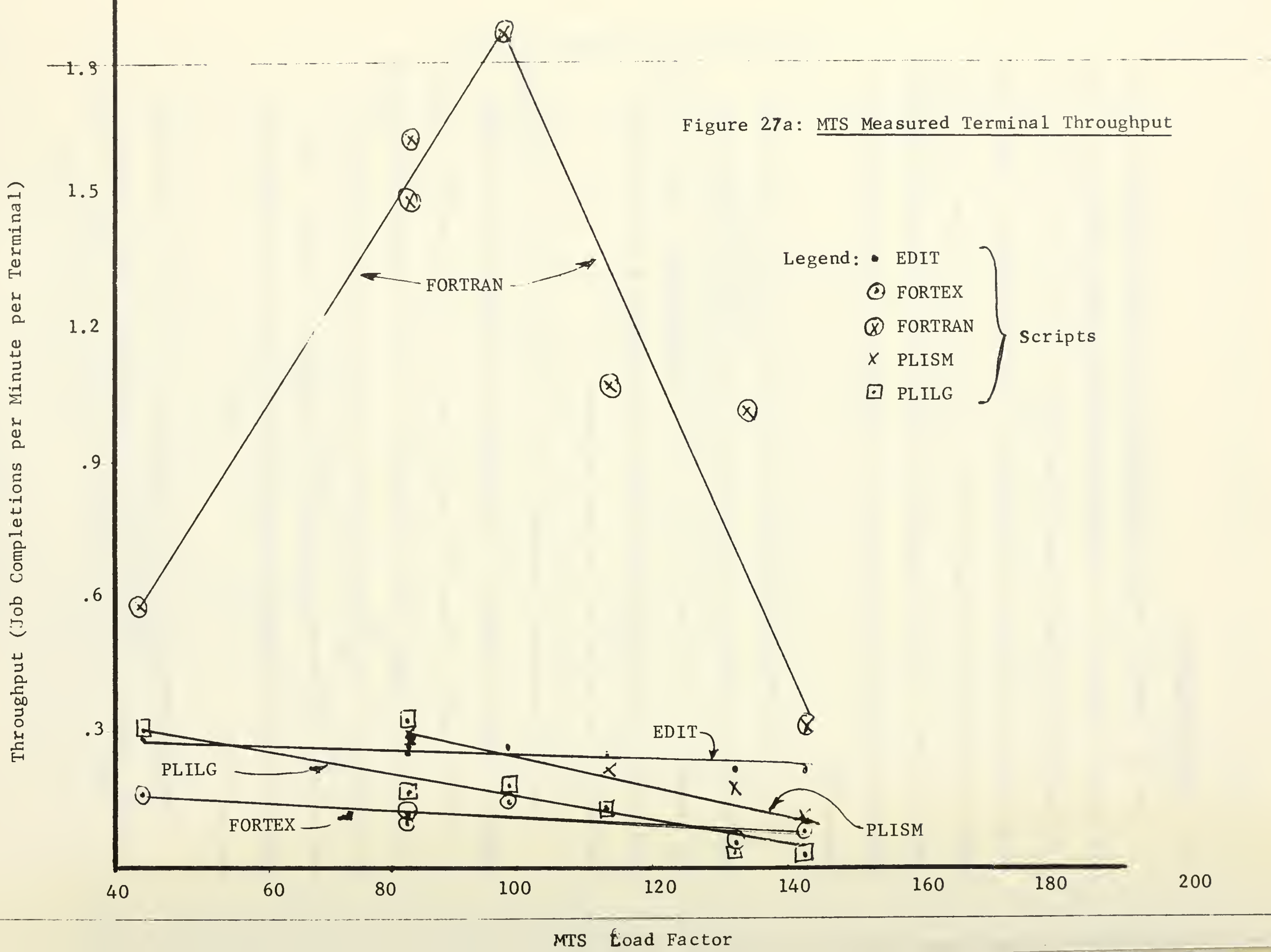


Figure 27a: MTS Measured Terminal Throughput

Figure 27b MTS Measured Terminal Throughput - Expanded Scale

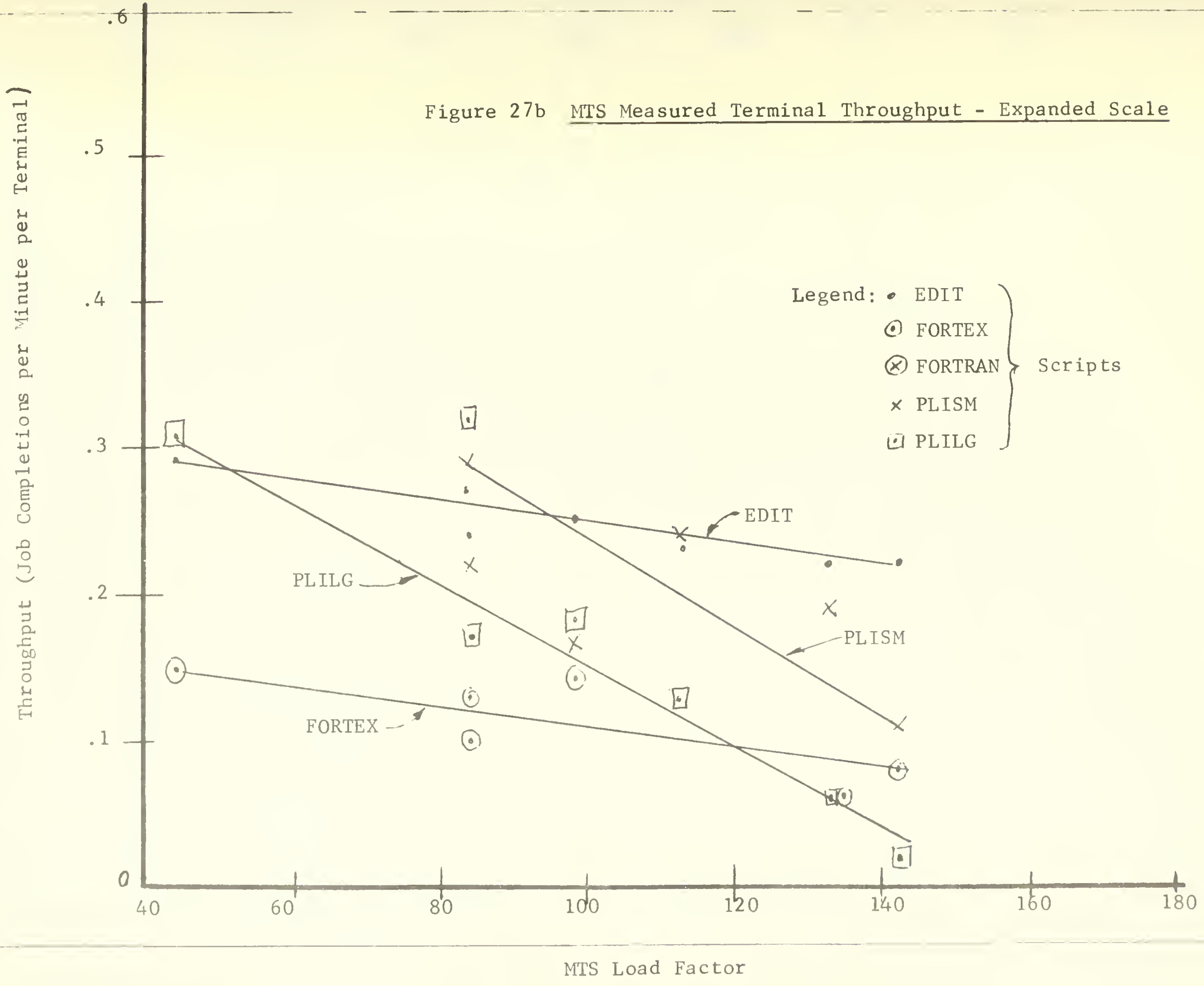


Figure 28a: MTS Total Measured Throughput for each Script - PLILG, FORTEX, PLISM

(Total measured throughput for all terminals running a particular script.)

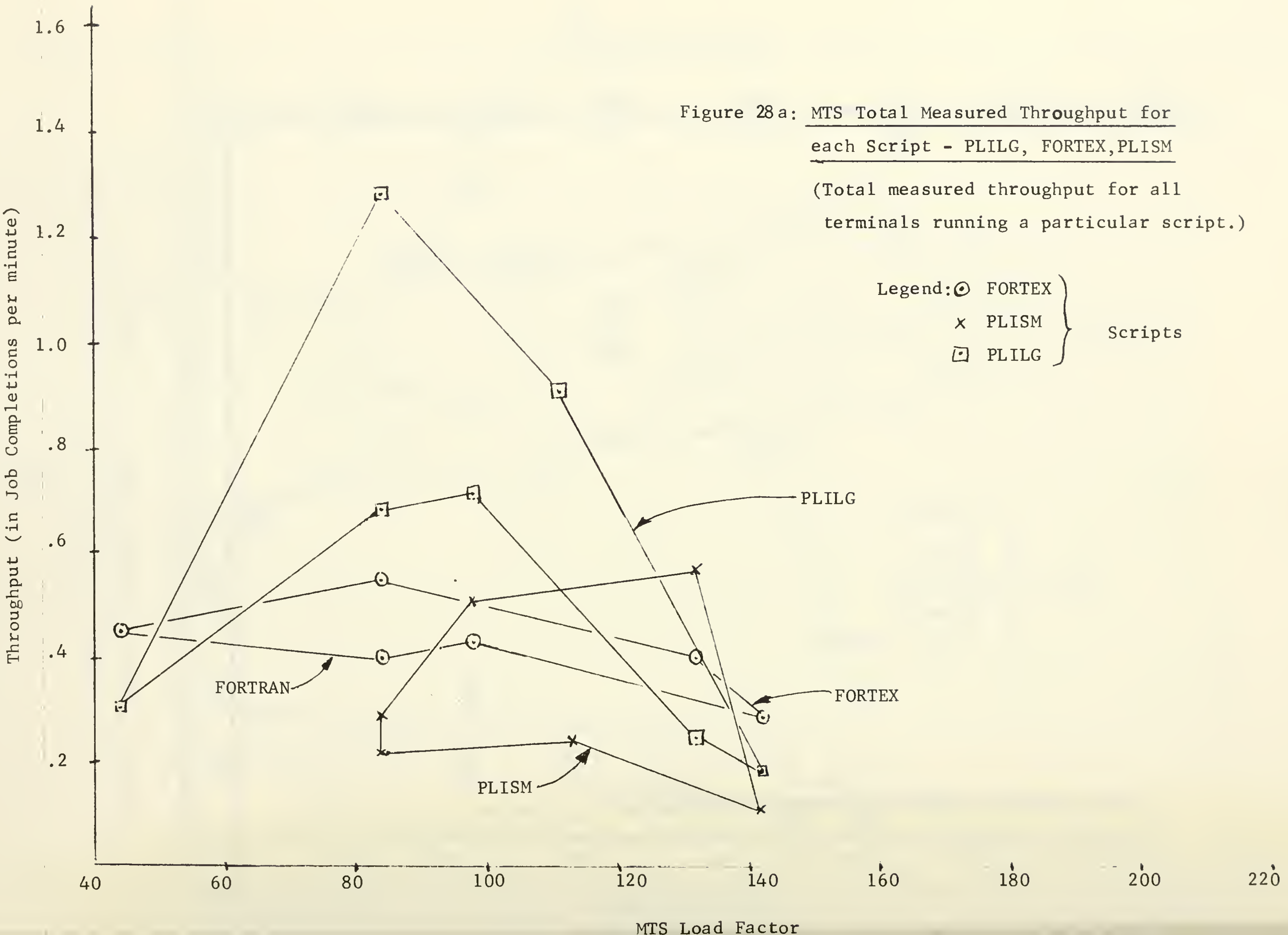
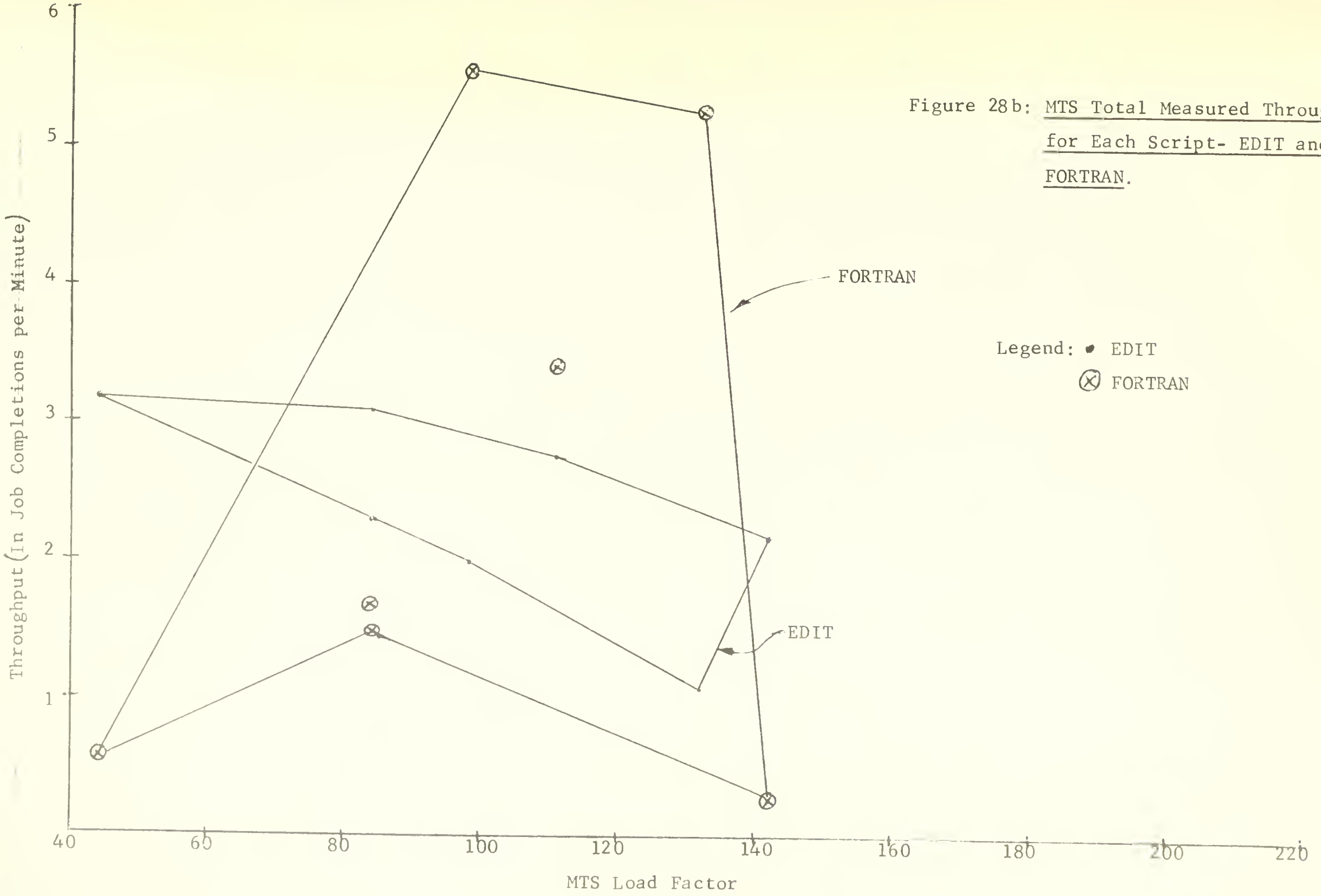


Figure 28b: MTS Total Measured Throughput for Each Script- EDIT and FORTRAN.



also consistent with those of previous tests on the other systems.

The MTS total measured throughput ranges from 14 job completions per minute at a load factor of 45 to 6 job completions per minute at a load factor of 140, as shown in Figure 29. The total throughput was subdivided into total EDIT throughputs and total non-EDIT throughputs which are also shown in Figure 29.

6.5.3 MTS Effective Progress Rates

The effective progress rates for MTS were obtained by dividing the mean terminal response times shown in Tables E1 and E2 by the stand-alone response times shown in Table E5. The MTS effective progress rates for each script is shown in Figure 30. The effective progress rates for EDIT and FORTEX scripts is almost constant at 0.75 and 0.1 respectively. The FORTRAN, PLISM and PLILG effective progress rates all decrease rapidly as the load increases and all are approximately the same. They start at about 0.7 for loads from 40 to 80, drop to 0.3 at 100 and then to 0.2 to 0.1 at load factors of 145.

The total effective progress rates and the subtotals for EDIT and non-EDIT scripts are shown in Figure 31. The total effective progress rate appears to have a hump at a load factor of 80 reaching a maximum value of over 12. In all cases the total effective progress rate was over 7 - meaning that the MTS system was operating at least 7 times as effective as a serial processor system.

Of course a large portion of the total effective progress rates was due to the EDIT scripts - anywhere from 3 to 9.5. However the

Figure 2 9: MTS-Total Measured Throughputs

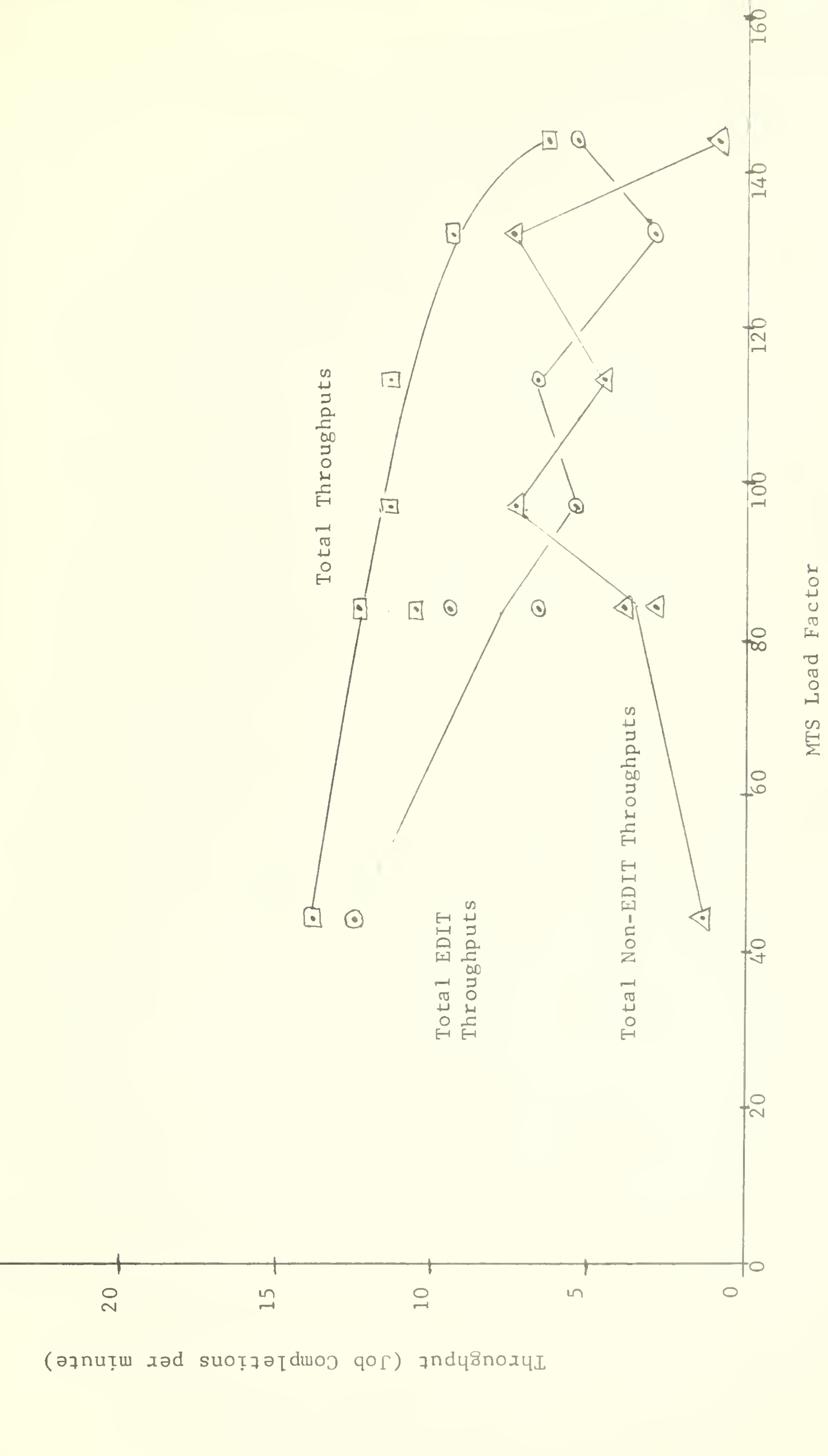


Figure 30: MTS Effective Progress Rates per Script

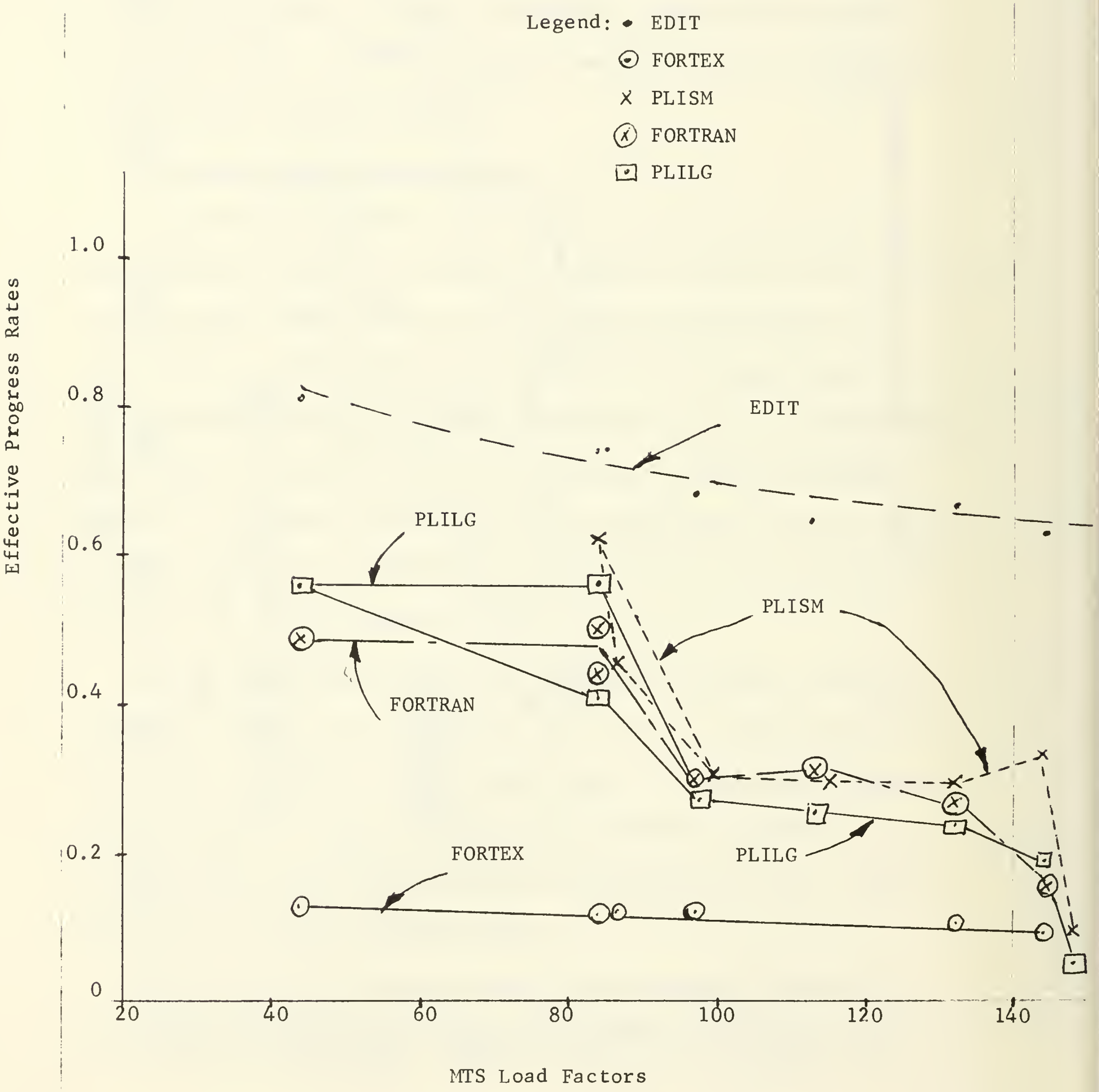
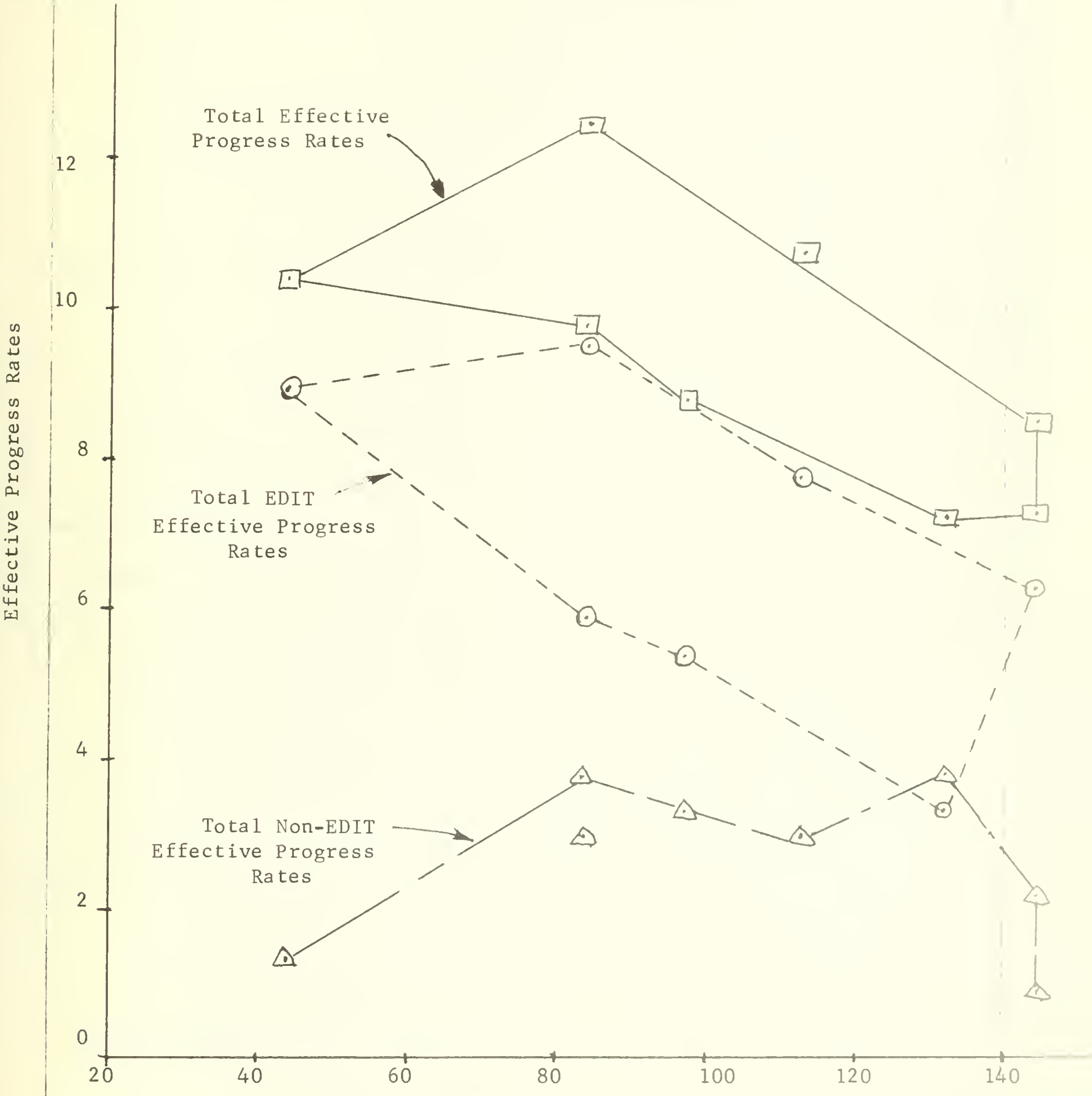


Figure 31: MTS Total Effective Progress Rates versus MTS Load Factor



MTS Load Factors

effective progress rate for non-EDIT scripts was also impressive, ranging from 1.5 at a light load to 3.9 at a heavy load. Except for the last part of Run R63 when the effective progress rate for non-EDIT scripts dropped to 0.94, the MTS system always operated better than a sequential processor for all loads, even when the EDIT scripts are not included in the total throughput.

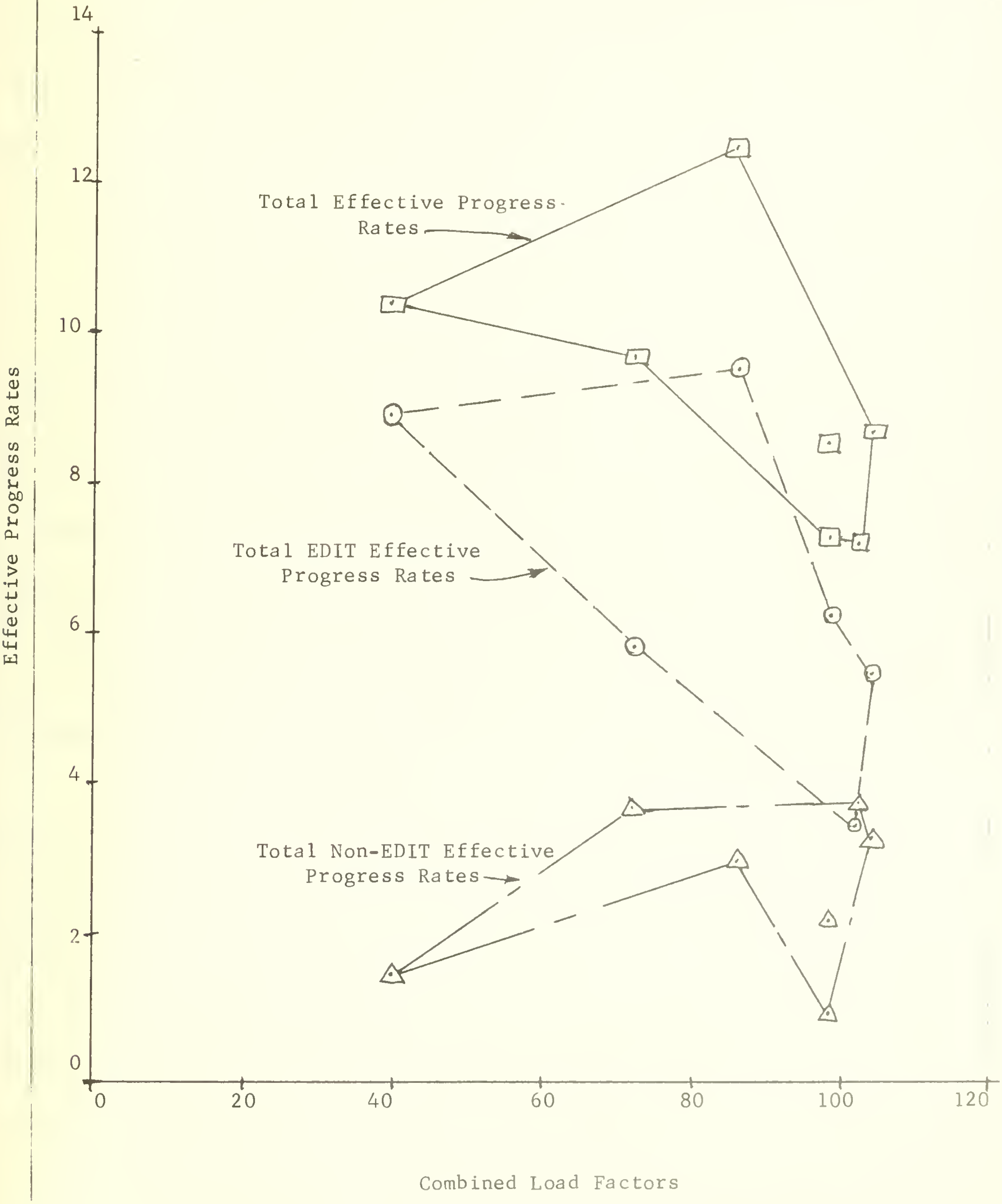
Figure 32 shows the same total effective progress rates as Figure 30, except they are plotted against the combined load factors. This figure will be used in the next section for comparison with CP performance.

6.6 CP and MTS Comparisons

This section compares the performance of the CP and MTS systems as measured in this project. Since one of the objectives of the project was to compare CP and TSS in the configurations at NPS, the CP tests used a different configuration than the MTS tests. To try and compensate for this disparity, the CP and MTS performances are sometimes compared directly, and sometimes compared with CP's performance improved by a factor of three. Since it was shown in subsection 6.4.1 that CP performance doubles when the amount of core memory is doubled, it is assumed that three would be a reasonable CP improvement factor when the amount of core memory is tripled. (The intermediate results in Table C10 of Appendix C also support this improvement factor, although it may be a little optomistic towards CP.)

The performance of CP and MTS was compared on three criteria: terminal response times, total throughputs and effective progress rates.

Figure 32: MTS Total Effective Progress Rates versus Combined Load Factors



6.6.1 CP and MTS Terminal Response Time Comparisons

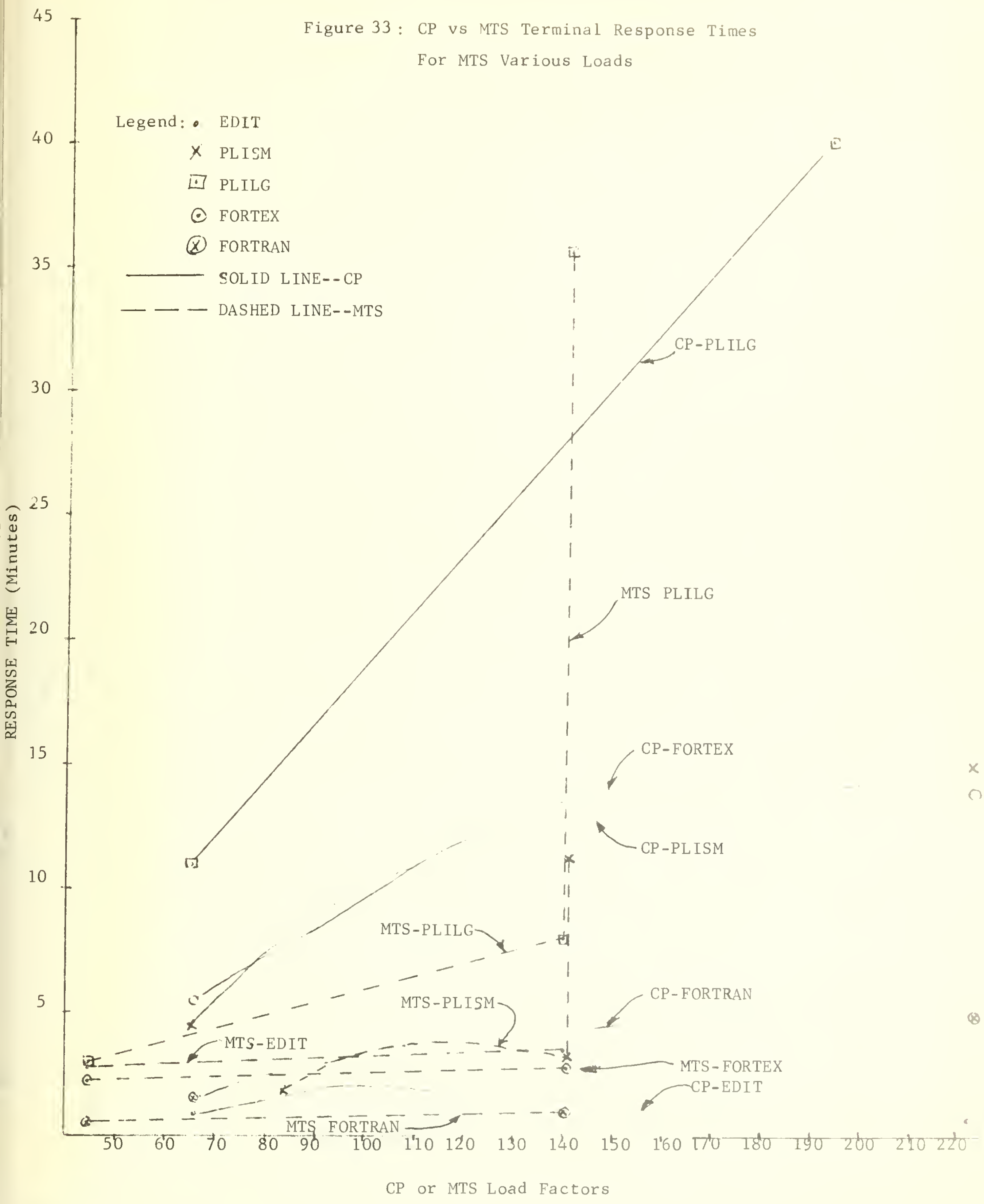
A comparison of the terminal response times for each script for CP and MTS is shown in Figure 33. Figure 33 is a composite of the CP response curves from Figure 2 and the MTS response curves from Figure 25. The MTS response times were much lower than the CP ones with two exceptions - one was for Run R63b when MTS had very poor response times*, and the other was for all EDIT scripts because of the extra 2 minutes of printing time used by MTS editor.*

Because CP had a serious configuration disadvantage, having only one core box and one processor compared to three core boxes and dual processors for MTS, the comparison shown in Figure 33 are repeated in Figure 34 with the CP response times reduced by a factor of 1/3. (This is equivalent in assuming the CP performance triples when the amount of memory is tripled.) Since the above comparison tends to indicate that CP was loaded more heavily than MTS - which was not the case -, a better comparison is made when the response times are plotted against the combined load factor, as shown in Figure 35, instead of against individual load factors shown above. Figure 35 is equivalent to combining Figures 20 for CP and 26 for MTS.

In both these figures, the MTS response is generally better than that for CP despite the tripling of the CP performance. The MTS responses for PLILG is better than CP's for all except the lightest load and the heaviest overload in Run R63b. The MTS responses for FORTEX and PLISM are almost always less than the lowest CP ones. The MTS FORTRAN responses

*Discussed previously in Section 6.5.1.

Figure 33: CP vs MTS Terminal Response Times For MTS Various Loads



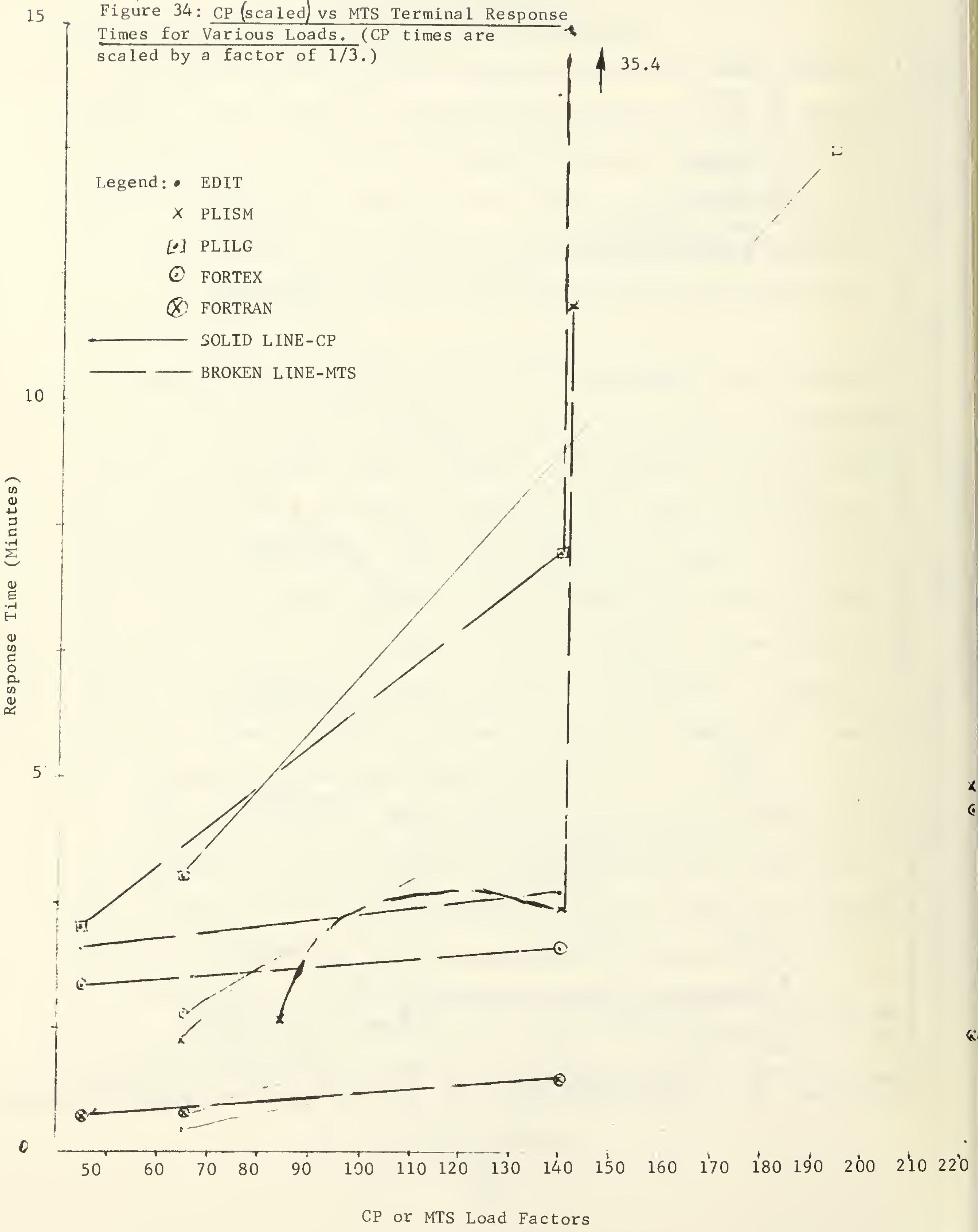
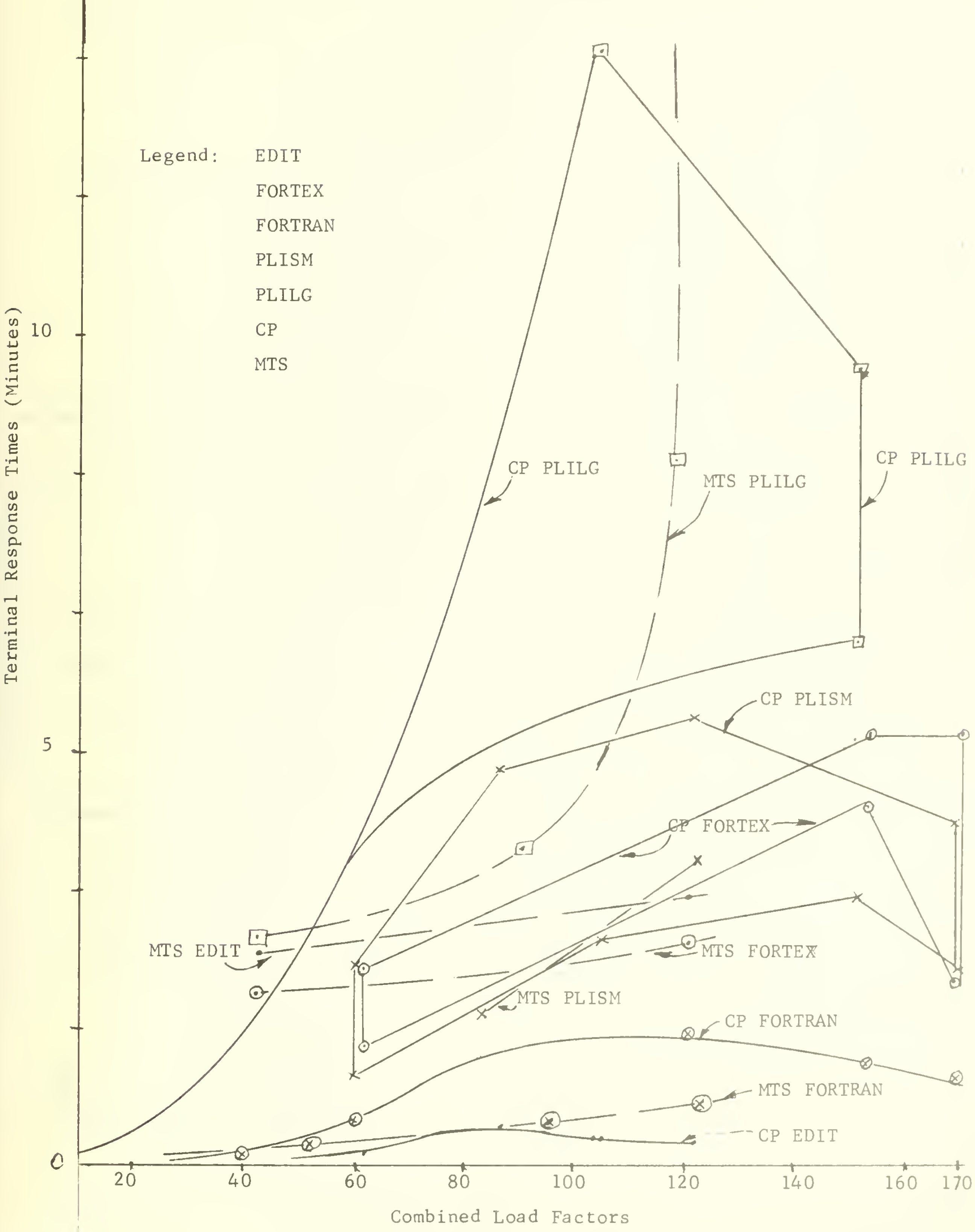


Figure 34: CP (scaled) vs MTS Terminal Response Times for Various Loads. (CP times are scaled by a factor of 1/3.)

Figure 35: CP (Scaled) versus MTS Terminal Response Times against Combined Load Factors. (CP times are scaled by a factor of 1/3).



are always much less than the CP equivalents. The only occasion when MTS response times are higher than the CP ones are the MTS EDIT responses, which have the extra 2 minutes of terminal printing times as discussed previously in Subsection 6.5.1.

Another comparison of the CP and MTS performance is shown in Figure 36 in which the terminal response times are plotted against equivalent run numbers. The MTS PLILG response times are lower than the CP scaled response times for all runs except the lightest and the heaviest load. The MTS PLISM responses are somewhat higher than the CP equivalent and the FORTRAN responses are about the same. Therefore, MTS and CP performances are approximately equivalent when the CP response times are reduced by a factor of one-third.

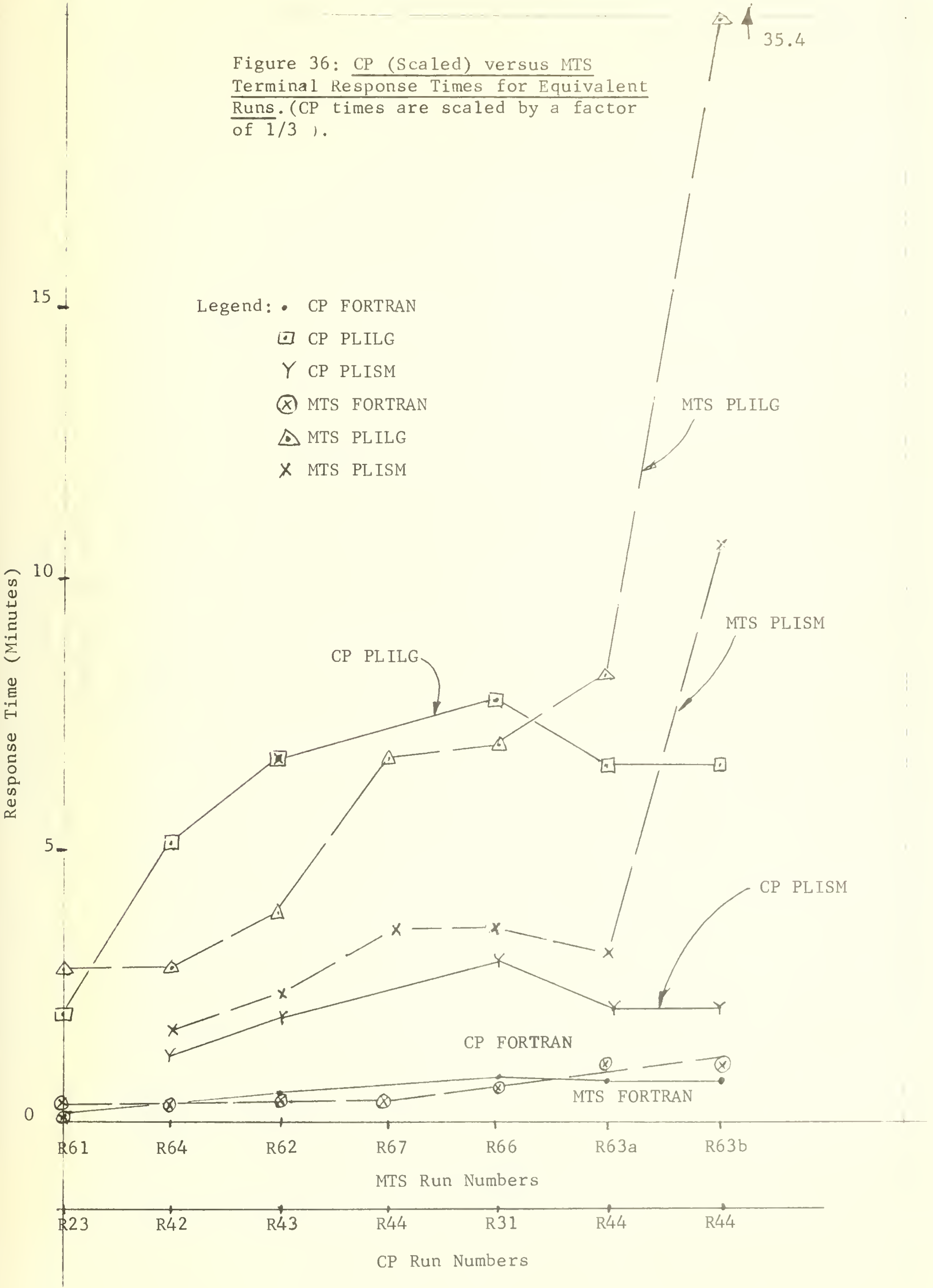
6.6.2 CP and MTS Throughput Comparisons

The total throughputs for CP and MTS are shown in Figure 37, which is a combination of the CP total measured throughput as shown in Figure 9 and the MTS total measured throughput as shown in Figure 29, both replotted against the combined load factor. The MTS total throughput is about double that of CP, ranging from 7 to 14 job completions per minute compared to 3 to 8 job completions per minute for CP. When the CP throughput are multiplied by three, the scaled total CP throughput is larger than the MTS equivalent for all except very heavy overloads (i.e., combined load factor over 100).

6.6.3 CP and MTS Effective Progress Rates

The CP and MTS total effective progress rates are shown in Figure 38,

Figure 36: CP (Scaled) versus MTS Terminal Response Times for Equivalent Runs. (CP times are scaled by a factor of 1/3).



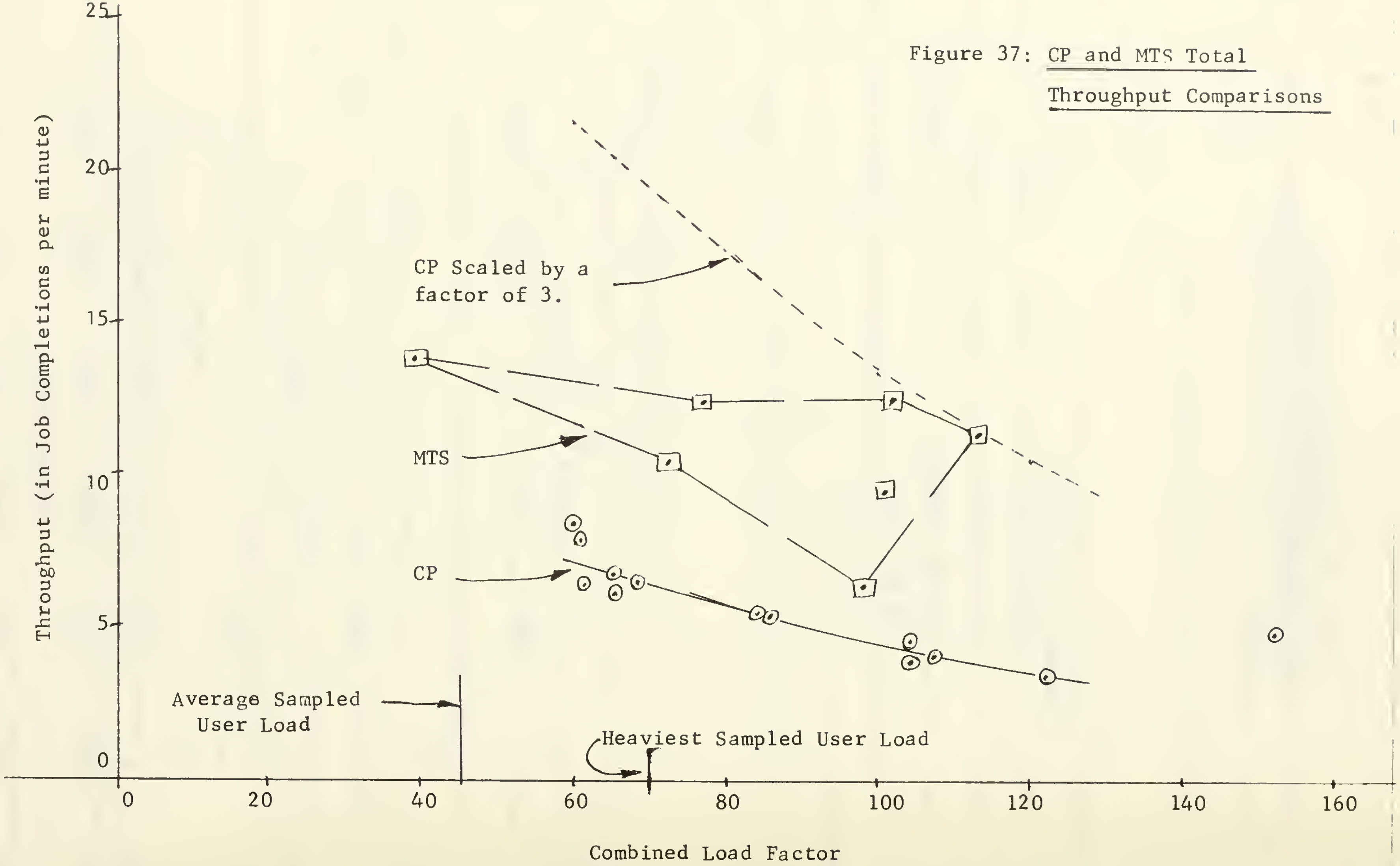


Figure 37: CP and MTS Total Throughput Comparisons

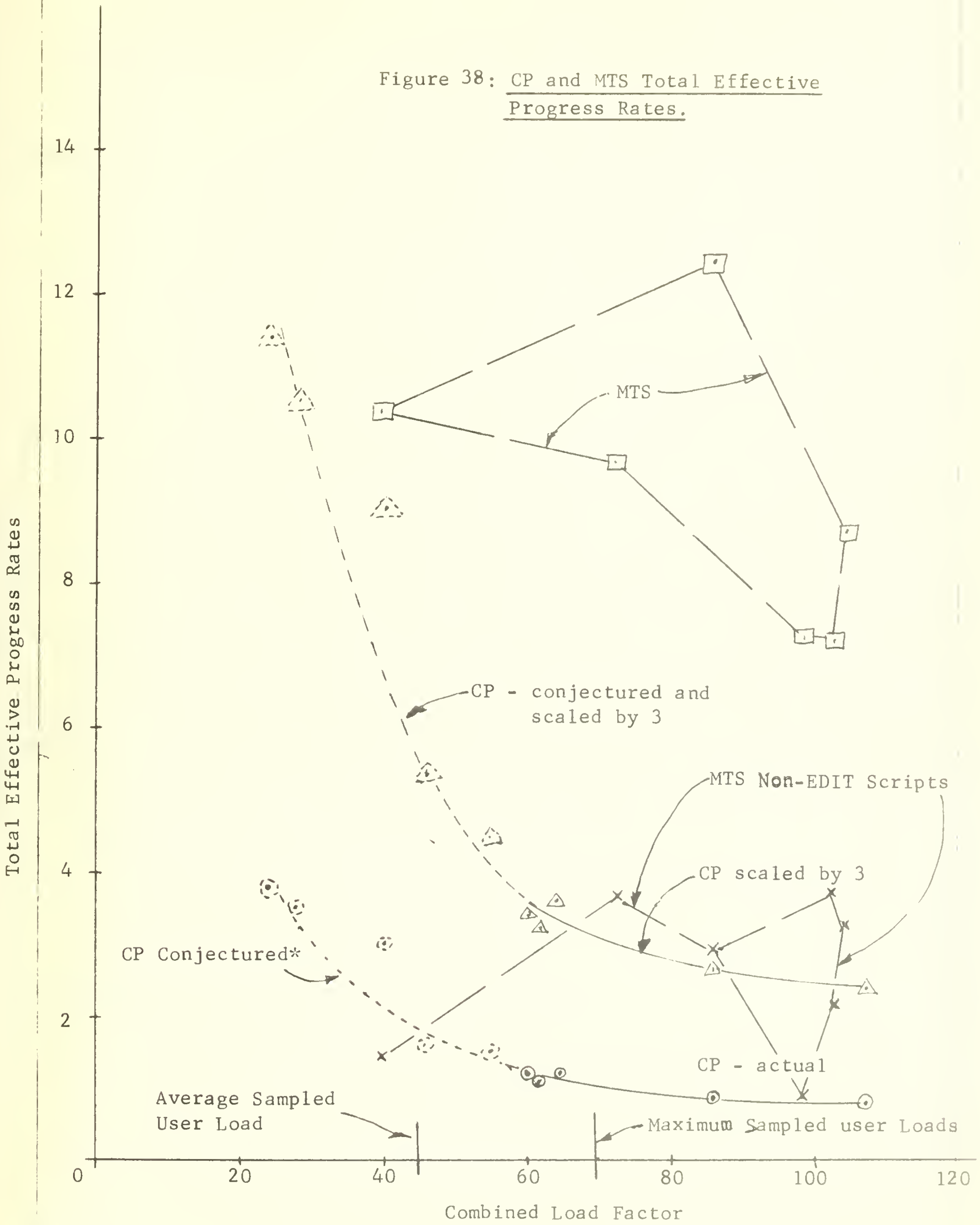


Figure 38: CP and MTS Total Effective Progress Rates.

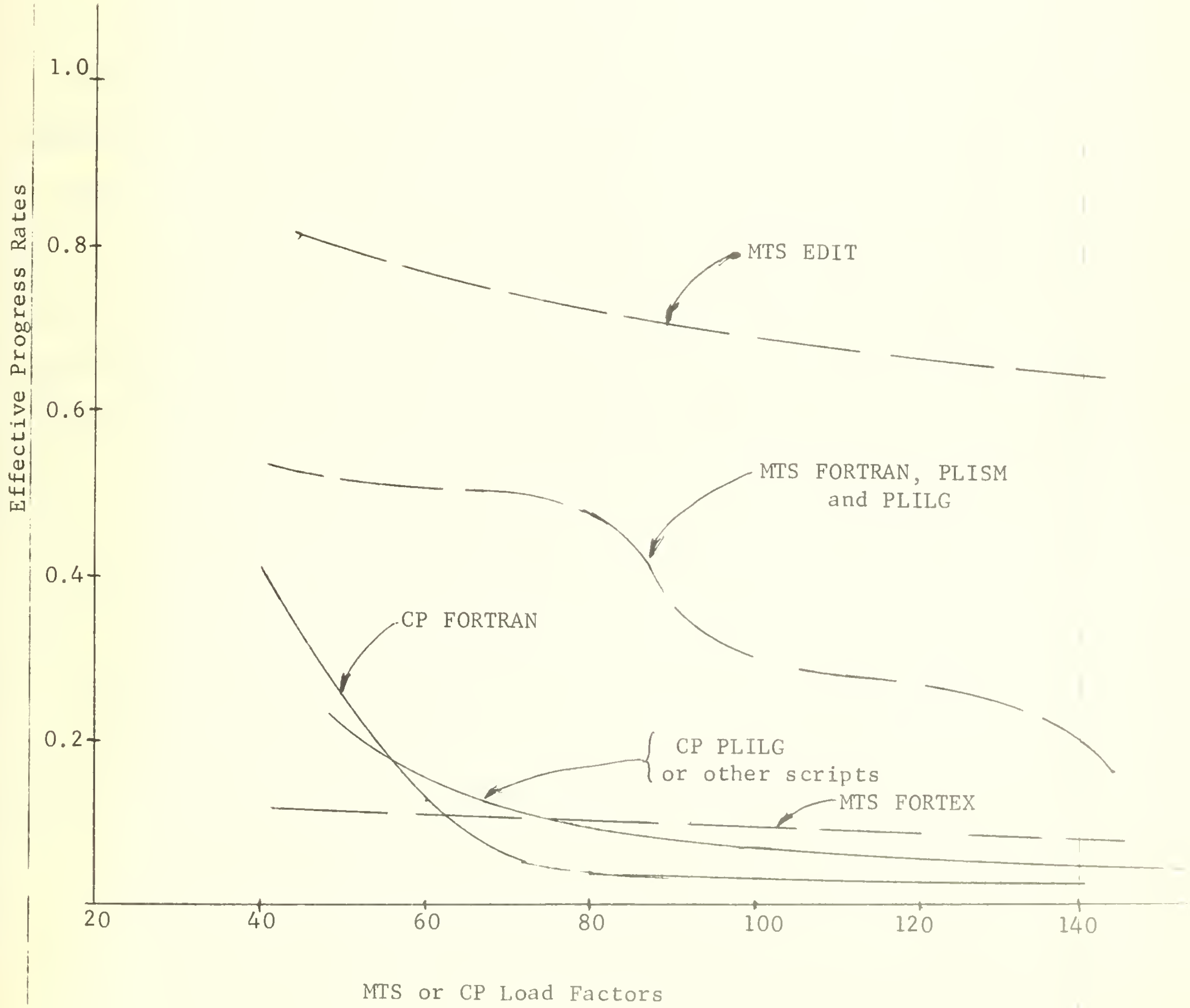
*as conjectured in Table 9 in Subsection 6.2.4.

which is a composite of the CP data in Figure 11 replotted against the combined load factor (actually using Table C7) and the MTS data in Figure 32. The CP data has been augmented at low loads by the conjectured effective progress rates as shown previously in Table 9.

MTS out-performed CP by a wide margin in total effective progress rates. In fact, MTS was substantially better than CP even after the latter's performance was multiplied by three, especially at medium to heavy loads. The MTS total effective progress rates for loads of 60 and above was 10 times better than that of unscaled CP results. (A combined load factor of 60 is below the maximum sampled user load.) Also, the MTS total effective progress rate is 5 times the value for CP at the normal user load. The MTS total effective progress rates for non-EDIT scripts are also shown in Figure 38 and exceed the scaled CP curve on 4 of the 7 runs. A fifth run is very close to the scaled CP curve and the sixth is at a low factor. Therefore, the total effective progress rates for the MTS compilation and execution scripts only is the same or better than that of the scaled CP with all scripts (including EDIT) on almost all the benchmarking runs.

Effective progress rates for some typical scripts for MTS and CP are shown in Figure 39. Again MTS out-performs CP by a wide margin on almost all conditions.

Figure 39: Some Typical Effective Progress Rates per ^cript for CP and MTS



6.7 CP, TSS and MTS Comparisons

Rather than repeat many of the figures already presented or variations of them, this section will provide references to simular graphs so that it is easy to make three system comparisons by making pair-wise comparisons.

6.7.1 Pair-Wise Comparisons

The terminal response times for the three systems can be compared by examining the CP and TSS response times in Figure 21 and examining the CP and MTS response times in Figures 34, 35 or 36. Since CP and TSS response times are approximately the same when CP has restricted resources (only 256k bytes of memory), and the CP times scaled by a factor of three are approximately equal to MTS response times, it is easy to conclude that MTS response times are three times better than those for TSS.

The total throughput for the three systems is a little more difficult to compare because of the limited TSS throughput data collected. However the throughput data for the FORTRAN and PLILG scripts can be compared by examinimg the CP and TSS calculated results in Figure 23 and the MTS measured results in Figure 27. Therefore a comparison of the total throughput of the three systems has to be limited to the comparison of CP and MTS systems as shown in Figure 37.

The effective progress rates of the three systems can not be compared because stand-alone response times are not available for TSS and therefore the effective progress rates for TSS can not be determined.

6.7.2 Performance at Typical Loading Conditions

As a summary, the three time sharing systems are compared at typical loading conditions with respect to the terminal response times and the total throughputs. (The total effective progress rates are not compared because there is no data for TSS). The three typical loading conditions are: the average sampled user load and the heaviest sampled user load and a heavy overload which is hereby defined as twice the average sampled user load. These three loads are determined by the terminal probing tests in Sections 5.3 and 5.4, and correspond to CP load factors of 50, 80 and 100, respectively, or the equivalents.

Therefore, Figure 40 is a summary of the terminal response times from the curves in Figures 2, 16 and 25 for CP, TSS and MTS, respectively. At a glance, Figure 40 indicates that TSS and CP provide approximately the same response times at the three selected loading points. Also CP and MTS provide approximately the same response times when the CP times are all divided by 3. On the other hand, the load has some effect on this last comparison. At the average user load, the scaled CP response times are generally better than MTS, but at the overload conditions the MTS times are generally better.

The normal user response times for FORTRAN are 1.0, 0.4 and 0.2 minutes for TSS, CP and MTS respectively. The PLILG response times under similar conditions are 5.8, 5.5 and 3.0 minutes, respectively.

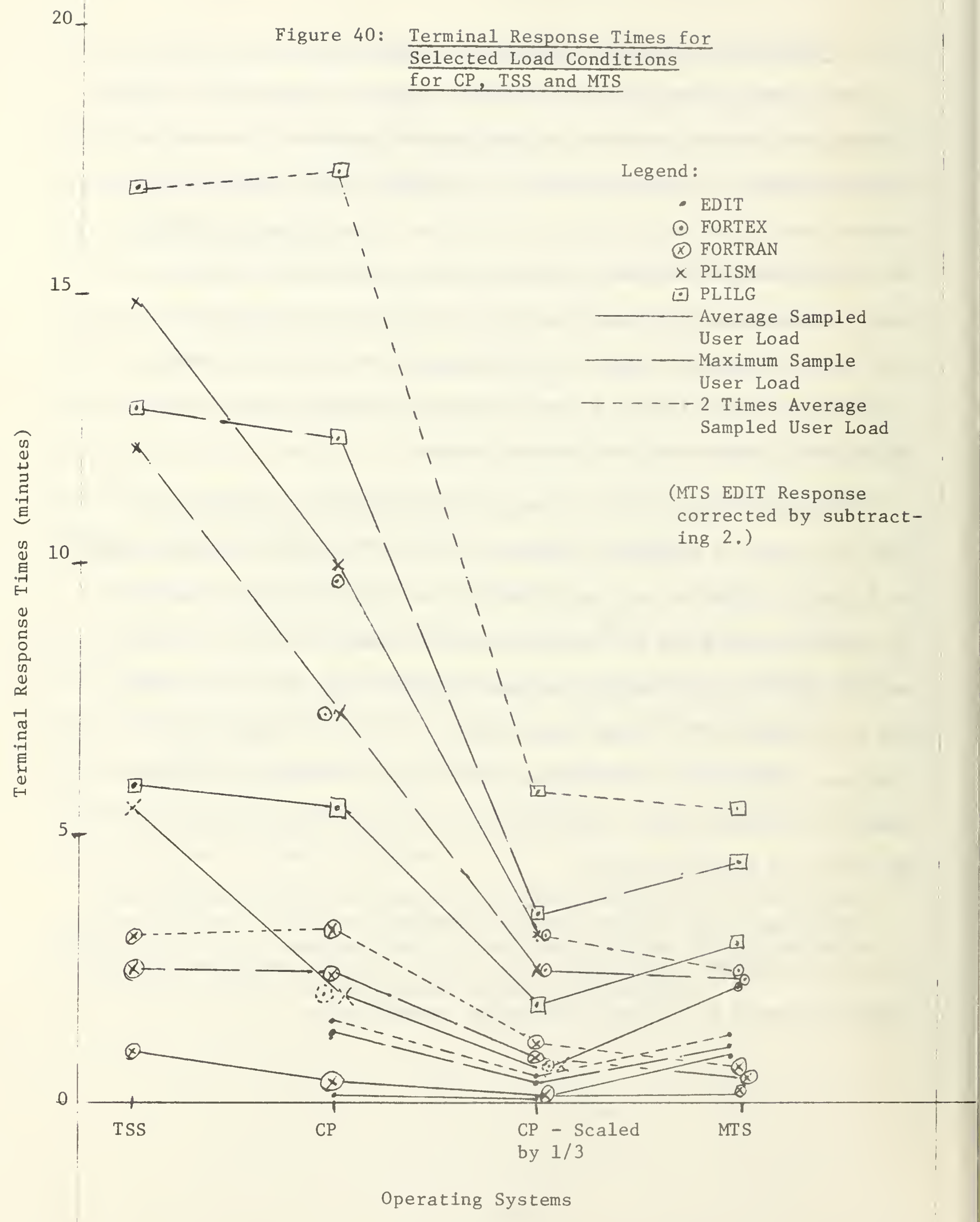


Figure 40: Terminal Response Times for Selected Load Conditions for CP, TSS and MTS

(MTS EDIT Response corrected by subtracting 2.)

The three time sharing systems are also compared with respect to the total throughput. The data for the total measured throughputs for the TSS and CP comparison was obtained from Figure 24, while the throughput data for the CP and MTS comparison was obtained from Figure 37. The summary, as shown in Figure 41, indicates TSS and CP have the same throughput at the heavy load and the overlaod conditions, but CP has better performance at light loads. The total measured throughputs for CP and MTS are approximately the same when CP's throughputs are multiplied by two instead of three.

This concludes the results and comparisons of the three time sharing systems. The next section compares the three systems with batch handling capabilities under batch benchmark loads.

6.8 Batch Benchmarking Results and Comparisons

This section presents the results of the batch benchmarking tests conducted on the TSS, OS/MVT and MTS operating systems and compares their performances. The batch benchmarking programs or jobstreams were described previously in Subsection 2.2.2 and Appendix B, and the tests performed were described in Section 3.2.

6.8.1 Batch Benchmarking Results

The results of the OS batch benchmarking tests are summarized in Figure 42. The results show that the three jobstreams take about the same total turnaround times on OS, varying from 22 to 27 minutes. Also there is relatively little difference between the results with two and three core boxes - which is very surprising considering the useable core is doubled in the second case.

Figure 41: Total Measured Throughput for Selected Loads for CP, TSS and MTS

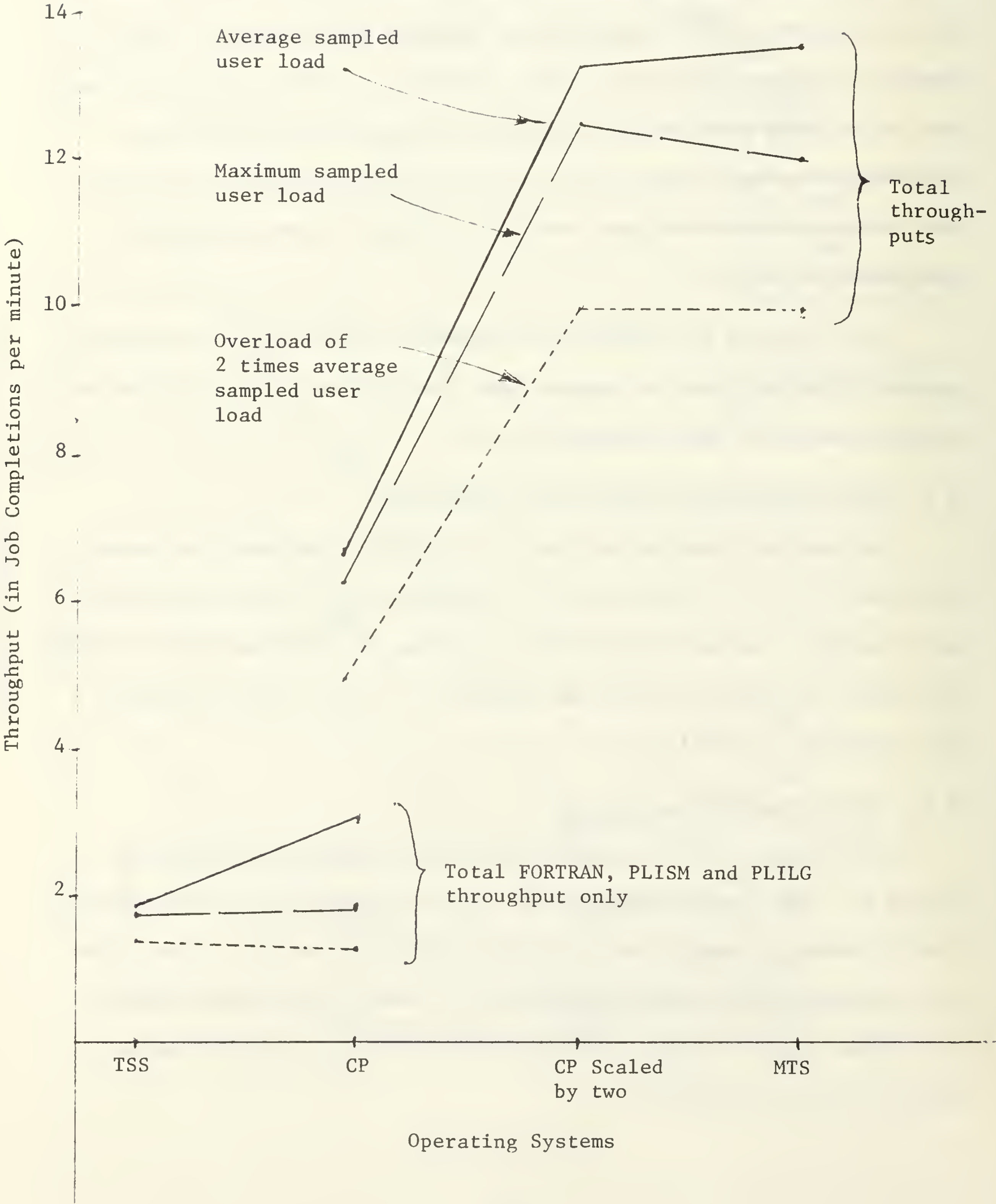
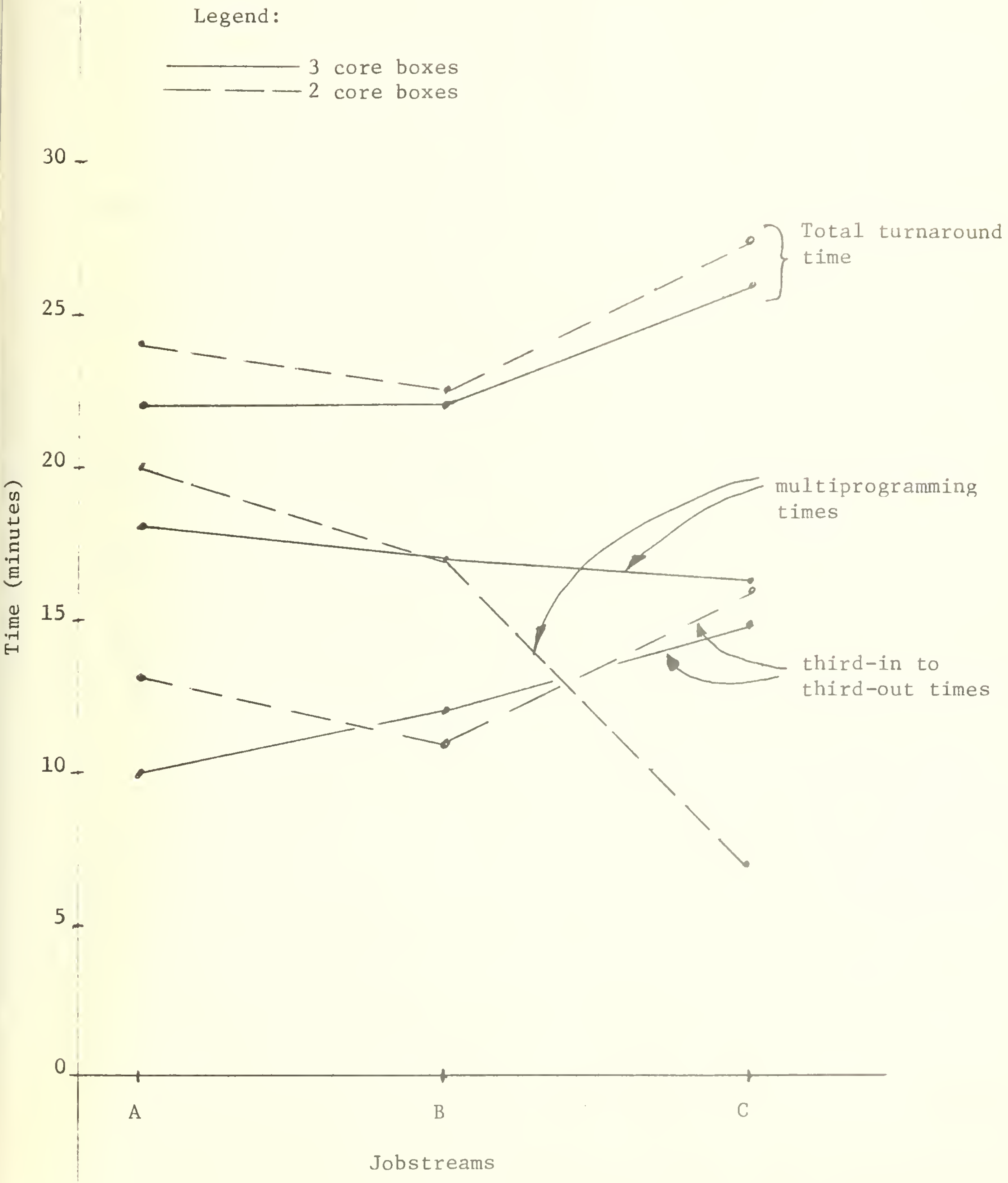


Figure 42: OS Benchmarking Results



The multiprogramming times - the times during which at least two jobs are in execution - vary from 17 to 20 minutes on Jobstream A and B but vary from 7 to 16 minutes on Jobstream C. The very low multiprogramming time with two core boxes indicated a very inefficient use of OS, since OS is operating as a serial processor for 20 minutes out of the 27 minutes. This benchmark must be somewhat atypical when the multiprogramming time can drop from 16 minutes to 7 minutes and the total turnaround time only increases from 26 to 27 minutes.

The third-in to third-out times - which represent the times in which at least three jobs are in the system - are also shown in Figure 42. These times also represent the time in which the system is loaded and vary from 10 to 16 minutes for the three jobstreams and the two configurations.

As an aside, some results from a hardware monitor are shown in Table 12, which indicate that the CPU wait time decreases from 65 percent to 47 percent during normal operation when the memory was increased from 512K bytes to 768K bytes [9]. This means an improvement in CPU utilization of 50 percent (i.e., (65-47)/(100-65)) when the extra core box is added. This means a much larger difference in performance with the extra core box would be expected under normal batch operation than that experienced in the batch benchmarking test results above. This suggests that the batch benchmarks do not take advantage of the extra memory available with 3 core boxes.

6.8.2 Batch Performance Comparisons

The comparison of TSS, OS and MTS under batch loading is shown in

Table 12: Hardware Monitor Results for Comparing OS/MVT Performance with 768K bytes vs. 512K bytes of Core under Normal Operating Load

EVENT	512K bytes no drum	768K bytes and drum	Ratios
CPU wait	65.18	47.13	1.38
CPU wait and channel not busy	29.73	26.07	1.14
CPU wait and channel busy	34.61	21.06	1.65
CPU wait, and channel not busy and MVTREX seek	3.51	2.22	1.58
CPU wait and channel not busy and MVTLNX seek	12.34	7.62	1.62
CPU wait and channel not busy and LINDA seek	2.87	0.12	23.9
CPU wait and channel not busy and SPOOL 1 seek	2.26	1.14	1.98
CPU wait and channel not busy and SPOOL 2 seek	6.03	2.15	2.8
CPU wait and channel not busy and SPOOL 3 seek	2.64	2.52	1.05

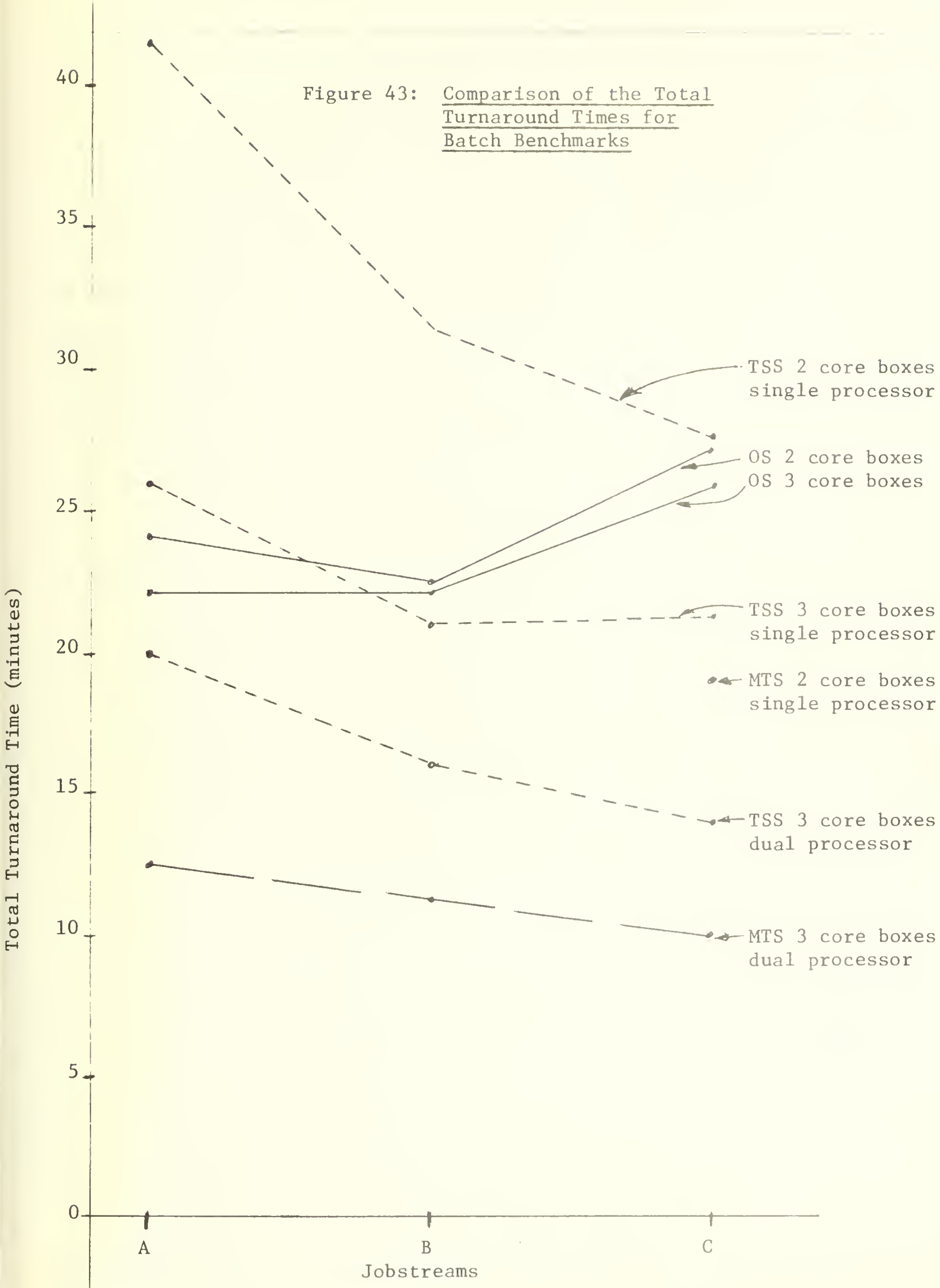
Figure 43. TSS with two core box simplex configuration had the poorest performance, especially on Jobstream A where it required 41 minutes for completion. On Jobstream C, OS with either 2 or 3 core boxes was almost as bad as TSS at 27 minutes. The OS performance on Jobstreams A and B was about the same as the TSS 3 core box simplex system on all three jobstreams with turnaround times of 21 to 26 minutes. The TSS 3 core box dual processor system performance was significantly better than the OS or other TSS performances, ranging from 20 minutes on Jobstream A to 14 minutes on Jobstream C.

The MTS performances were already superior to all others. The MTS performance with 2 core boxes and a single processor was better than TSS with three core boxes and a single processor on Jobstream C (but was not as good as the TSS duplex 3 core box performance). The MTS dual processor three core box performance was the best of all with turnaround times of 12.5 minutes and 10 minutes for Jobstreams A and C respectively. Compared to OS with compatible configurations*, the MTS performance was 45 percent better than that of OS on Jobstream A and 61 percent better than that of OS on Jobstream C.

Before continuing, one comment on the batch benchmarks is in order. Since Jobstreams A and B contain 2 300K byte jobs and Jobstream C contains 3 of these large jobs, OS must serially process these jobs with either 2 or 3 core boxes. However if the largest jobs had been 250K bytes, then OS would have been able to multiprogram the large jobs when it had 3 core

*OS can not run with two processors

Figure 43: Comparison of the Total Turnaround Times for Batch Benchmarks



boxes, resulting in a considerable improvement in performance.

If the improvement had been the same as that experienced in normal operating conditions as presented in Subsection 6.8.1, i.e., 50 percent, then the OS total throughput times would have been 16, 14 and 18 minutes for Jobstreams A, B and C respectively. This would have meant that with nearly equivalent configurations*, OS would have out-performed TSS on 2 of the 3 benchmarks. TSS and MTS performances would not change appreciably, since they use paging instead of fixed memory allocation. Of course, this comparison is only a conjecture based on the observed improvement in CPU utilization during normal OS operation and not on an analysis of the jobstreams.

*Of course OS would have only a single processor while TSS had 2 processors.

6.8.3 Comparison of MTS with CP Plus OS

Since one of the objectives of this research was to compare the performance of MTS with that of the split CP-OS system, this section presents a tentative comparison of MTS supplying both batch and terminal services to that of the split system with CP supplying the terminal services and OS supplying the batch services. Although the testing of MTS with both batch and terminal services has not yet been accomplished, some analysis based on the results in this report are now presented.

Consider the situation in which the batch benchmarking loads are applied to MTS and, as soon as they are completed, the terminal benchmarking loads are applied to MTS. The question is how many jobs will be completed by MTS compared to the total number completed by both CP and OS during the same time period. Consider the following:

(1) The time for OS with 2 core boxes to complete all three jobstreams, as shown in Figure 43, is 73 minutes (24 + 22 + 27).

(2) The time for MTS with the full system to complete all three jobstreams is 34 minutes (12.5 + 11.3 + 10).

(3) The difference between MTS time and OS times is 39 minutes, which is available for processing terminal jobs.

(4) Since the total throughput for CP with one core box at the average sampled user load is 6.7 jobs per minute according to Figure 41, the total throughput in 73 minutes is 490 jobs (6.7 x 73).

(5) Since the total throughput of MTS with the full system at the average sampled load is 13.6 job completions per minute according to Figure 41, the total throughput in 39 minutes is 530 jobs (13.6 x 39) or 40 jobs higher than the CP throughput in 73 minutes.

Furthermore, if the average sampled loading condition used above is replaced with the heaviest sampled user loading condition, the CP throughput changes to 360 job completions (4.95 x 73), compared to 390 (10 x 39) for MTS which is a savings of 30 jobs or 8 percent for MTS.

Therefore, at both the average and the maximum sampled user loads, the MTS processes the batch and terminal benchmarks faster than CP plus OS, even when MTS processes the batch and terminal jobs as two sequented groups.

The Non-EDIT throughput comparisons are also of interest. For example, at the maximum sampled user load, the total Non-EDIT throughput for CP is 110 jobs in 73 minutes (73 x 1.5 from Figure 9) compared to 117 jobs in 39 minutes for MTS (39 x 3 from Figure 32) or a difference of 6 percent in the terminal throughputs. However if the load is increased to more than double the average sampled user load (load factors of 95 to 130), the difference becomes much more significant. The total CP Non-EDIT throughput stays relatively constant at 110 to 150 jobs in 73 minutes (Figure 9), but the MTS equivalent increases significantly to 200 to 300 jobs in 39 minutes. which is approximately double that of CP. Therefore, the total batch and terminal Non-EDIT throughputs for the 73 minute period would be about 25 percent higher for MTS than for the split CP and OS system, assuming the improved terminal performance is average over the batch performance.

In all probability, the actual MTS throughputs would probably be somewhere between the 5 percent and 25 percent figures presented above because MTS, with its multiprogramming feature, would probably obtain some overlap of the batch and terminal job processing, and it is really unfair to CP to exclude the EDIT throughputs from the comparisons. In any case, the MTS performance is better than the split CP and OS system.

Section 7

CONCLUSIONS

The following conclusions are made from the results presented in this report. In each case, the reference to the appropriate section or figure is also given.

(1) A basic set of six terminal scripts were developed for loading and benchmarking the performance of different time sharing operating systems (Subsection 2.2.1).

(2) The load factor concept was introduced as a method of calibrating loads. Although the method of selecting the load factor weights was rather arbitrary, the results were good. In most cases the response times, throughputs and effective progress rates were all plotted against the load factors (Section 4.3).

(3) It was verified that the fixed script approach -- whereby each terminal was assigned one and only one script -- is a realistic and accurate technique for terminal benchmarks. The fixed scripts were easier to control, produced results that were easier to analyze and made computer performance easier to compare than mixed scripts, and yet they both produced approximately the same loading effects (Section 5.2 and Table 6).

(4) From the terminal probing tests it was found that the minimum, average, and the maximum sampled user loads corresponded to CP load factor of 25, 50 and 80 respectively. The corresponding MTS load factor were 25, 46 and 74, respectively, and the corresponding combined load factors were

25, 45 and 70 (Tables 7 and 8). Since the benchmarking tests had load factors from 30 to 200, the benchmarking runs represented, light, normal heavy and very heavily overloaded conditions.

(5) CP under average sampled user load provided terminal response times of 0.4, 1.3, 3.4 and 4.5 minutes for FORTRAN, FORTEX, PLISM and PLILG scripts, respectively. These values increased to 1.4, 4.1, 11.1 and 15, respectively, at the maximum sampled user loads (Section 5.4 and Table 7).

(6) Although the CP total effective progress rate was about 3 with the average sampled user load, it was reduced to 0.8 when the load was increased up to the maximum sampled user load. This meant that CP normally operated with a multiprogramming improvement factor of 3, but during overloads CP operated at only 80 percent of the capacity of a serial processing system (Subsection 6.2.4 and Figure 11).

(7) From the above conclusion, it is further concluded that it behooves all designers of time sharing systems to incorporate the load factor concept into their systems and to inhibit initiation of new jobs when the load factor reaches a critical load factor value. (MTS uses this concept in its latest version but CP does not.)

(8) The CP operating system, with 256K bytes of core memory, a single processor and slower disks, out-performed TSS with 768K bytes of memory, two processors and faster disks over almost all tested conditions (Figures 40 and 41 or Section 6.4).

(9) Cperating the IBM 360/67 as a split system with OS providing batch services and CP providing terminal services provided better performance than running the full system under TSS, because the batch throughput was obtained for essentially free. (See Conclusion 8 above.)

(10) CP operating with 512K bytes of core memory reduced the response times to about one half and produced twice the throughput as CP with 256K bytes of memory (Figure 22).

(11) MTS out-performed CP under the configurations tested (Section 1.4) by a factor of about three. The MTS terminal response times were approximately 1/3 those of CP (Figure 34 to 36 and 40). The MTS total throughputs were 2 times those of CP (Figures 37 and 41), while the MTS total effective rates were about 10 times those of CP (Figures 38 and 39).

(12) The MTS total effective rates were very impressive ranging from 7.3 to 12.6. The total Non-EDIT effective progress rates were equally impressive ranging from 2 to 3.8 at all loads except the lightest benchmark and the heaviest overload. This meant the MTS operated much better than a series processor (Subsection 6.5.3 and Figure 32).

(13) TSS out-performed OS on batch-only benchmarks by a small margin. This is a conditional conclusion because there is a possibility that the conclusion is the results of the batch benchmark design which was biased against the 768 K byte OS system instead of differences in actual performance. (See discussion in Subsection 6.8.2.)

(14) MTS out-performed TSS and OS on batch-only benchmarks by a wide margin. The MTS total turnaround time was less than half that for OS.

(15) When MTS processed all the jobs in the batch benchmarks and then processed terminal benchmarking jobs, the total throughput for MTS was about five percent better than that processed by CP and OS running separately for the same time periods.

(16) When the total Non-EDIT throughputs were compared, under conditions as specified in Conclusion (15), the MTS total throughputs were seven percent higher CP plus OS totals (Figure 29 for MTS). However, when the Non-EDIT throughputs were compared at higher load factors of 95 to 130, MTS processed nearly twice as many terminal jobs for a total savings of about 25 percent (Subsection 6.8.3).

Based on the above conclusion, it is suggested that MTS provides a superior performance to the split CP-OS system. It is probably that MTS would overlap the execution of terminal and batch job executions to achieve even better performance than described above.

In his thesis, E. F. Hinson has concluded that there are several other advantages besides performance improvements for switching to MTS. In particular the MTS system is a much easier system to learn and to use than the two systems that are currently being used. The ease of learning is an important consideration in any university environment.

Therefore it is strongly recommended that the administration of IBM 360/67 computer centers give serious consideration to the adoption of the Michigan Terminal System for providing both batch and terminal services.

The next major step in evaluating and implementing the MTS system is to confirm that the actual MTS performance is, in fact, as good or better than that suggested above for suitable combinations of batch and terminal loadings. An introduction to the Michigan Terminal System and its features can be obtained from [3] or [16].

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Appendix A

TERMINAL SCRIPTS USED FOR BENCHMARKED COMPARISONS CP/67, TSS/360 AND MTS TIME SHARING SYSTEMS

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The purpose of this appendix is to describe in detail and to supply the listing for the scripts used in comparing three time sharing systems for the IBM 360/67. This appendix is to be used in conjunction with a paper entitled "An Empirical Comparison of CP/67 and TSS/360 Time Sharing Systems," published in the Proceeding of the Fifth International Conference on Systems Sciences, 1972, pp 206-208 [17]. Further details on the results of the tests can be obtained from an MS Thesis with the same title by W. R. Haines and J. H. Porterfield, Jr., June 1972, US Naval Postgraduate School [2].

The basic types of programs included in benchmarks are:

- Compilations
- Executions
- Editing

The compilations are represented by 3 programs; a 74 card Fortran compilation called FORTRAN, a small 47 card PL/I compilations called PLISM and a large 434 card PL/I compilation called PLILG. The execution programs are represented by a compute-bound Fortran execution program called FORTEX and a page-bound Fortran execution program called PAGE. PL/I programs were chosen to represent large complex compilers which have a large working sets (30 to 40 pages) and use large amounts of CPU time, thus degrading the performance of any time sharing system. It is believe that these jobs can also represent the load from assembler jobs. The Fortran programs were chosen because they represent the major jobs at the installation under investigation. Each program was activated by a script. In simple cases the script simply printed the time, called the program and then repeated itself. For most of the tests a terminal executed a single script allowing more rigid control on the test and more accurate analysis. In some cases mixed scripts were used in which a single script on a given terminal was a combination of several simple scripts. As stated in the paper, this provided a means for checking the bias in the fixed-script technique of comparing performance. Before discussing the scripts in detail some of the major evolutionary steps in their development will be presented.

Basically four changes were made to the scripts after the first CP test run:

1. The EDIT script was changed to reflect the think time of the user by activating the EDIT script for 5 seconds out of every 60 seconds of connect time. This was accomplished by hitting the terminal ATTN button after 5 seconds and then restarting the terminal after 55 seconds. If several terminals were editing the starting time were staggered. (For CP only.)

2. The ratio of edit to run (meaning compilation + execution) programs was changed from 5:1 to 2:1, increasing the load by about 2 1/2 times. Also it was felt that 2:1 ratio represented a beter estimation of the actual load.

3. The EXEC routines in CP were rewritten to print the desired times at the terminals.

4. An organized plan was formed for combining the scripts on various terminals to represent various loads from medium to heavily overload. The plan was to start with medium load and change the job mix (i.e. benchmark or set of scripts) every 15 minutes with the number of terminals varying from 12 to 22. (Note the load is much more dependent on the run to edit ratio than the number of terminals.)

After run two, it was concluded that the scripts in the present form could be used for a valid comparison of CP and TSS but that further changes in the scripts would make the comparison more realistic; these were:

1. Although the ratio of two edits to one running program seems realistic, it didnot place a heavy enough load on the system. Thus it was decided to vary the ratio of edit to run programs from 1:1 to 1:5 which means that almost all the 24 terminals were compiling or executing programs in the worst case.
2. Since the CP editor had an advantage over the TSS editor by not filing the results after every edit command, it was decided to make the EDIT program function more than the TSS editor (Normally, CP uses an in-core editor and only changes the file on disk when told to do so by the user, but TSS files the results of every edit command on disk. This makes a significant difference in the paging load.) The rational for this change was that most users would probably only make a few changes to their program before filing it and recompiling. This change was accomplished by shortening the EDIT script so that it took about 5 seconds (of real time) to complete and by making it non-looping. Every 60 seconds the EDIT script was initiated again. (This change increased the CP paging load from the EDIT script significantly.)
3. The number of loops in the FORTEX program before an output was produced was decreased from 10^7 to 10^6 in order to increase the amount of output and the accuracy of measuring the load from this script.

4. A program PAGE was added to the benchmark to represent page-bound execution job. The program is a matrix multiplication program that has its matrix elements spread over several pages.

After run three there was one change made to the way the FORTEX script called the program, in order to make it more consistant with the other programs and to print the time at fairly regular intervals. Instead of the program looping, the EXEC program was made to loop and call a non-looping version of FTN. (The self-looping version can be obtained from the one shown later by moving the WRITE statement labelled 1000 to the first statement.)

The final scripts were as follows. (CP examples will be used unless otherwise noted.)

1. EDIT - A CP EXEC routine that performs several edit functions such as locating a string, moving the pointer up and down and typing some output. In CP the routine was non-looping, took about 5 seconds of real time to complete, and was activated every 60 seconds to represent user think time. In TSS a simulated timer was used to wait for 55 seconds before repeating. In MTS the printing of 10 lines was used as an effective delay.
2. FORTEX - A routine to simulate compute-bound jobs. It executes a loop of 2 additions, a test and a branch 10^6 times and then prints a short line and gives the time.
3. FORTRAN - A routine that compiles an average size (75 card) Fortran program.
4. PLISM - A routine that compiles a small (47 card) PL/I program.
5. PLILG - A routine that compiles a reasonable sized (434 card) PL/I program.
6. PAGE - A routine to represent page-bound jobs. It sequentially accesses a single element from a page of a 30-page matrix.

Table 1 shows the equivalent names for the CP, TSS and MTS scripts and program names. The listing attached include the following actual scripts and programs as run in comparing the time sharing systems:

1. CP EXEC routines for fixed script tests,
2. All the programs used by CP,
3. The CP mixed scripts,
4. The CP mixed script for probing the load under normal operating conditions,
5. The CP EXEC routines used by the mixed scripts,
6. The TSS PROCDEF routines, including the fixed scripts and the mixed scripts. (Note ALL 4 include the PAGE program but there is no equivalent in CP.)
7. MTS files for the fixed scripts (equivalent to CP EXEC routines).

Table 1 EQUIVALENT NAMES FOR SCRIPTS

	CP and TSS			MTS	
ALIAS	EXEC and PROCDEF		Program	Script file	Program
(name in paper)	Looping version	non-looping	Name	(looping)	
EDIT	-	P	LOOP	EDITS	EDITOR
FORTEX	CRUN	CRUNN	FTN *	FORTX	FORTEX
FORTRAN	COMPI	COMPII	LOOP	FORTRAN	FORCOMP
PLISM	COMP2	COMP22	HAI3	PLILIT	PLISM
PLILG	COMP	COMPP	FINK	PLIBG	PLILG
PAGE					
PAGE	PG	PG	PAGE	PAGER	PAGE
Mixed Scripts	ALL1,ALL2, ALL3**	MIX	all above***	--	--

* In actual TSS tests FTN was called FEXEC. Also in latest version of CP tests FTN compiled LOOP instead of the proper program. This version was only used in MIX and not in any of the comparison runs.

** TSS also contained ALL 4 which included PAGE

*** except PAGE, but ALL 4 in TSS did contain PAGE.

ALIAS EDIT

```
OFFLINE READ       P         EXEC
&TYPEOUT ALL TIME
&BEGSTACK
L /50/
N 10
TOP
FILE
&END STACK
EDIT LOOP FORTRAN
&TIME
```

ALIAS FORTEX

```
OFFLINE READ       CRUN      EXEC
&TYPEOUT OFF TIME
BLIP $
LOAD FTN (XEQ)
&TIME
&GOTO TOP

OFFLINE READ       FTN       FORTRAN
        I=0
10      I=I+1                                                            FTN00
        A=2. +2.                                                         FTN00
        IF (I.EQ.1000000) GOTO 1000                                      FTN00
        GOTO 10                                                          FTN00
1000    WRITE (6,2000)                                                   FTN00
2000    FORMAT ('***********')                                           FTN00
        END                                                              FTN00
                                                                         FTN00
```

ALIAS FORTRAN

```
OFFLINE READ       COMPI     EXEC
&TYPEOUT ALL TIME
BLIP $
FORTRAN LOOP
&TIME
&PRINT **COMPILATION COMPLETE**
&GOTO TOP
```

ALIAS PLISM

```
OFFLINE READ       COMP2     EXEC
&TYPEOUT ALL TIME
BLIP $
PLI HAI3
&TIME
&PRINT **COMPILATION COMPLETE**
&GOTO TOP
```

ALIAS PLILG

```
OFFLINE READ       COMP      EXEC
&TYPEOUT ALL TIME
BLIP $
PLI FINK
&TIME
&PRINT **COMPILATION COMPLETE**
&GOTO TOP
```

```
    7NEERING',/,' 620 COMMUNICATIONS MANAGEMENT',/,' 817 NAVAL MANAGEMEPAU00540
    8NT',/,' 999 P.G. SCHOOL STAFF')                                   PAU00610
     WRITE (6,2)                                                       PAU00560
  2  FORMAT ('1',26X,'YEAR CURR PHONE',40X,'NO.OF LAST DUTY')          PAU00570
     WRITE (6,3)                                                       PAU00580
  3  FORMAT (' NAME',17X,'RANK GRP   NO. NUMBER  WIFE      ADDRESS',14XPAU00590
    1,'CITY  CHILD  STATION',17X,'SMC',/)
     WRITE (6,4)                                                       PAU00610
  4  FORMAT ('+','----',17X,'---- ---   --- ------  ----      -------',PAU00620
    114X,'----  -----  -------',17X,'----',//)                         PAU00630
 30  READ (2,8,END=50)XNA,RANK,NYR,NCRS,NTEL,WIFE,ADDR,CITY,NDPN,DUTY  PAU00630
    2,SMC                                                              PAU00650
     WRITE (6,9)XNA,RANK,NYR,NCRS,NTEL,WIFE,ADDR,CITY,NDPN,DUTY,       PAU00650
    1SMC                                                               PAU00670
   9 FORMAT (1X,19A1,2X,4A1,2X,I2,3X,I3,1X,I7,1X,9A1,1X,5A4,2X,A1,6X,I PAU00670
    11,4X,5A2,14X,I4)                                                  PAU00680
     GO TO 30                                                          PAU00700
 50  WRITE (6,7) DATE                                                  PAU00710
  7  FORMAT (///,40X,5A4)                                              PAU00720
 91  CONTINUE                                                          PAU00730
     STOP                                                              PAU00740
     END                                                               PAU00750
```

ALIAS PLISM

```
FFLINE READ       HAI3      PLI
NEWRAP: PROC OPTIONS (MAIN);                                           HAI00010
TRY:     BEGIN;                                                        HAI00020
         DCL I FIXED DEC (3) INITIAL (1);                              HAI00030
         DCL (ROOT,X,X1,XJ,XI) FLOAT DEC (16) INITIAL (0);             HAI00040
         DCL E FIXED DEC (3) INITIAL (0.0001);                         HAI00050
         DCL BUFFER CHAR (80);                                         HAI00060
         DISPLAY ('INPUT') REPLY (BUFFER);                             HAI00070
         DISPLAY (BUFFER);                                             HAI00080
         GET STRING (BUFFER) LIST (XJ);                                HAI00090
         DCL (D,DJ,DI) FLOAT DEC (8) INITIAL (30);                     HAI00100
AGAIN:   XI=XJ;                                                        HAI00110
         IF DF((XI))=0 THEN GOTO TRY;                                  HAI00120
         XJ=XI-F((XI))/DF((XI));                                       HAI00130
         DI=DJ;                                                        HAI00140
         DJ=ABS(XJ-XI);                                                HAI00150
         IF DJ>E THEN                                                  HAI00160
STUP:         IF DJ>DI THEN                                            HAI00170
                   GOTO TRY;                                           HAI00180
              ELSE DO;                                                 HAI00190
                   IF I>20 THEN                                        HAI00200
                        GOTO TRY;                                      HAI00210
                   ELSE DO;                                            HAI00220
                        DISPLAY ('AT ITERATION '||I||' X'||I||'='||XJ); HAI00230
                        I=I+1;                                         HAI00240
                        GOTO AGAIN;                                    HAI00250
                   END;                                                HAI00260
              END;                                                     HAI00270
         ELSE                                                          HAI00280
              IF ABS (F((XJ)))>E THEN                                  HAI00290
                   GOTO STUP;                                          HAI00300
              ELSE DO;                                                 HAI00310
                   DISPLAY ('ROOT = '||XJ);                            HAI00320
                   STOP;END;                                           HAI00330
         DCL F ENTRY (FLOAT DEC(16)) RETURNS (FLOAT DEC (16));         HAI00340
F:       PROC (X) FLOAT DEC (16);                                      HAI00350
         DCL X FLOAT DEC (16);                                         HAI00360
         X=X**2-EXP(X)-3;                                              HAI00370
         RETURN (X);                                                   HAI00380
         END F;                                                        HAI00390
         DCL DF ENTRY (FLOAT DEC (16)) RETURNS (FLOAT DEC (16));       HAI00400
DF:      PROC (X) FLOAT DEC (16);                                      HAI00410
         DCL (X,Y) FLOAT DEC (16);                                     HAI00420
         Y=X-1;                                                        HAI00430
         X=2*X-X*EXP(Y);                                               HAI00440
         RETURN (X);                                                   HAI00450
         END DF;                                                       HAI00460
         END NEWRAP;                                                   HAI00470
```

ALIAS PAGE

```
OFFLINE READ       PG        EXEC
&TYPEOUT OFF
CP Q U
&TIME
& PAGE
&TIME
&GOTO TOP

OFFLINE READ       PAGE      FORTRAN
      DIMENSION A(1030,30)
5     WRITE (6,100)
      DO 10 I=1, 1030
      DO 10 J=1, 30
10    A(I,J)=100.+50.
100   FORMAT(' START OVER')
      STOP
      END
```

ALIAS FORTRAN

```
OFFLINE READ       LOOP      FORTRAN
C     PROGRAM TO COMPILE THE ROSTER OF SUBMARINE OFFICERS ATTACHED TO
C     THE NAVAL POST GRADUATE SCHOOL
      DIMENSION XNA(19),RANK(4),WIFE(9),ADDR(5),DUTY(5),DATE(5)
C     READ THE NUMBER OF DATA CARDS NOT INCLUDING THE YELLOW ONE, THE
C     NUMBER OF COPIES OF THE DIRECTORY DESIRED, AND THE DATE
      READ(5,1)NCAR,NCOP,DATE
  1   FORMAT(2I4,5A4)
C     THIS LOOP READS ALL THE DATA CARDS AND PUTS THE DATA ON DISK
      DO 90 I=1,NCAR
      READ(5,8)XNA,RANK,NYR,NCRS,NTEL,WIFE,ADDR,CITY,NDPN,DUTY,SMC
   8  FORMAT (19A1,4A1,I2,I3,I7,9A1,5A4,A1,I1,5A2,I4)
  90  WRITE (2,8)XNA,RANK,NYR,NCRS,NTEL,WIFE,ADDR,CITY,NDPN,DUTY,SMC
      END FILE 2
C     THIS LOOP PRINTS OUT THE ROSTER, REWINDS THE DISK AND CONTINUES
C     DOING THIS UNTIL NCOP COPIES ARE PRINTED.
      DO 91 I=1,NCOP
      REWIND 2
      WRITE (6,10)
  10  FORMAT ('1',24X,'DIRECTORY OF SUBMARINE OFFICERS ATTACHED TO THE N
     1AVAL POSTGRADUATE SCHOOL',///,' 1. THIS DIRECTORY IS UNOFFICIAL AN
     2D IS INTENDED PRIMARILY FOR SOCIAL REFERENCE.',//)
      WRITE (6,11)
  11  FORMAT (' 2. THE SUBMARINE LIASON OFFICER IS LCDR PHIL OCONNELL.
     1HIS OFFICE IS LOCATED IN ROOT',/,'    HALL, ROOM 214, ENGINEERING
     2SCIENCE CURRICULUM OFFICE. PHONE NUMBER 646 2426.'//)
      WRITE (6,12)
  12  FORMAT (' 3.  THE SUBMARINE OFFICERS SOCIAL CHAIRMAN IS LCDR  RAY
     1 ANDERSON, PHONE 373 5150.',//)
      WRITE (6,13)
  13  FORMAT (' 4. THE CHAIRMAN OF THE SUBMARINE WIVES GROUP IS  JANE
     1 WHITE, PHONE 372 7053.',//)
      WRITE(6,14)
   14 FORMAT (' 5. DOLPHIN PLAYING CARDS, NAPKINS, CALENDARS, COOKBOOKS,
     1ETC, CAN BE OBTAINED OR ORDERED THROUGH',/,'  MRS JOAN EGAN, PHONE
     2 375 1710.',//)
      WRITE (6,15)
  15  FORMAT (' 6. CHANGES OR ADDITIONS TO THIS DIRECTORY SHOULD BE  BRO
     1UGHT TO THE ATTENTION OF THE SUBMARINE LIASON OFFICER',/,'  OR THE
     2 SOCIAL CHAIRMAN.')
      WRITE(6,5)
   5  FORMAT (//////////,1X,'CITY LEGEND:',//,' C CARMEL',11X,' H CARMEL
     1 HEIGHTS      V CARMEL VALLEY      D DEL REY OAKS      M MARINA',/,'
     2P MONTEREY PEEN CC       T MONTEREY      B PEBBLE BEACH      G PACIFI
     3C GROVE        S SEASIDE',/,' A SALINAS       Q BOQ',///)
      WRITE (6,6)
  6   FORMAT (' CURRICULUM CODE:',/,' 360 OPERATIONS ANALYSIS',/,' 367 M
     1ANAGEMENT (COMPUTER SYSTEMS)',/,' 368 COMPUTER SCIENCE',/,' 372 ME
     2TEOROLOGY',/,' 380 ADVANCED SCIENCE',/,' 440 OCEANOGRAPHY',/,' 460
     3 ENGINEERING SCIENCE',/,' 461 BACHELOR OF ARTS/SCIENCE',/,' 521 NU
     4CLEAR ENGINEERING',/,' 530 WEAPONS ENGINEERING',/,' 535 UNDER WATE
     5R PHYSICS',/,' 570 NAVAL ENGINEERING',/,' 590 ENGINEERING ELECTRON
     6ICS',/,' 600 COMMUNICATIONS ENGINEERING',/,' 610 AERONAUTICAL ENGI
```

ALIAS PLILG

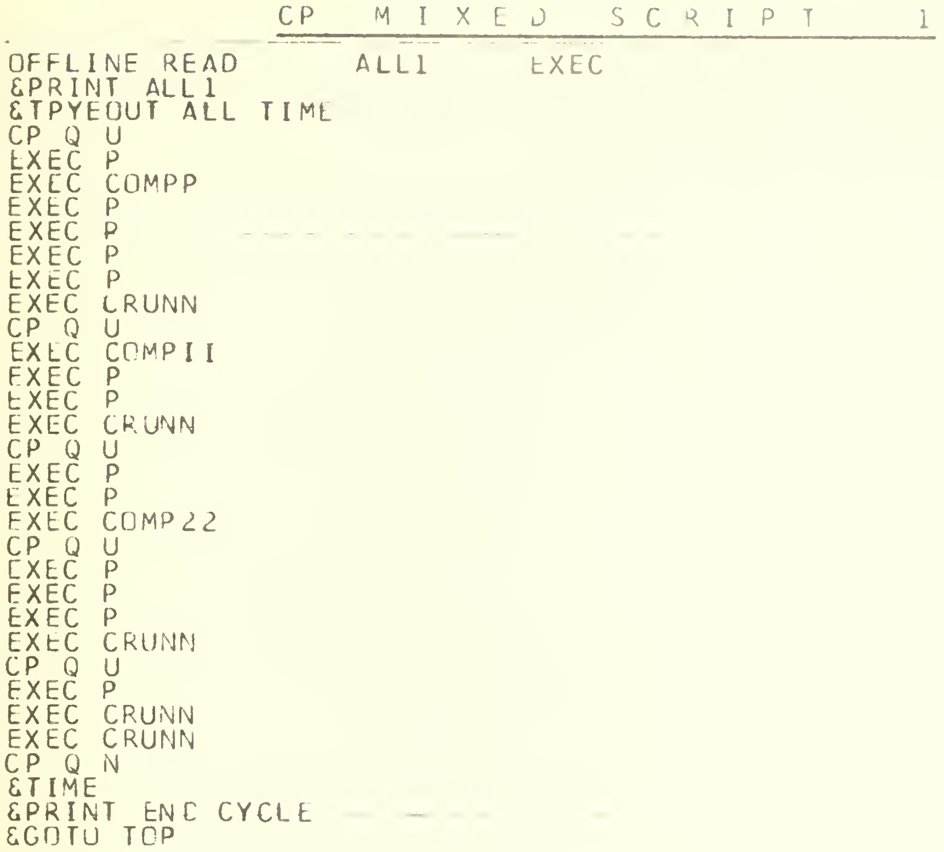
```
FLINE READ        FINK       PLI
ROJECT:PROC OPTIONS(MAIN);


      /* THIS PROGRAM WAS DONE BY THE COOPERATIVE EFFORTS OF
         J. BAIRD, B. HAINES, R. SPENCER, AND R. WOOLS   */


      /* THIS PROGRAM CONSTRUCTS A RING STRUCTURE USING THE
         26 LETTERS OF THE ALPHABET AND USES THESE LETTERS
         , WHICH CORRESPOND TO THE FIRST LETTER OF A PERSON'S
         LAST NAME, AS ENTRY POINTS TO BUILD A SUBRING
         STRUCTURE OF RECORDS CONTAINING DATA ITEMS: LAST
         NAME, FIRST NAME, OCCUPATION, CITY, AGE.
         THE PROGRAM ALLOWS ONE TO INSERT NEW RECORDS,
         DELETE RECORDS, CHANGE RECORDS, LOCATE RECORDS
         ACCORDING TO LAST NAME AND FIRST NAME, AND PRINT
         A LISTING OF ALL RECCRDS IN THE SYSPRINT FILE  */


       DCL ALPHABET CHAR(26) INIT('ABCDEFGHIJKLMNOPQRSTUVWXYZ');
       DCL ANSWER  CHAR (10)VAR ;
       DCL BUFFER CHAR(80);
       DCL SYSIN FILE STREAM ENVIRONMENT(F(80));
            OPEN FILE(SYSIN);
       DCL(FIRST_LTR,FRONT,BACK) PTR;
       DCL(NLAST,NFIRST,NOCC,NCITY,OLD_LAST,OLD_FIRST) CHAR(10);
       DCL (POSITION,LISTING) FIXED BIN(1) INIT(0);
       DCL NAGE CHAR(3);
       DCL BUILD ENTRY (CHAR(10));
       DCL BUILD_REC ENTRY (PTR,PTR) ;
       DCL LOOK_UP ENTRY (CHAR(10),CHAR(10)) RETURNS (PTR);
       DCL BUILD_ALPHA ENTRY (PTR) RETURNS (PTR);
       DCL FIND ENTRY (CHAR(10), CHAR(10)) ;
       DCL SYSPRINT FILE STREAM PRINT ENV (F(120));
       DCL ALPHA_ARRAY (26) PTR;
       DCL LABEL LABEL;
       DCL ERROR ENTRY(LABEL);


       DCL 1 ALPHA BASED (ALPHA_PTR),
            2 LTR CHAR(1),
            2 NEXT_LTR PTR,
            2 LIST_PTR PTR;


       DCL 1 RECORD BASED(NEW_RECORD),
            2 NAME,
                 3 LAST CHAR(10),
                 3 FIRST CHAR(10),
            2 OCCUPATION CHAR(10),
            2 CITY CHAR(10),
            2 AGE CHAR(3),
            2 NEXT_RECORD PTR;


     /* THIS BLOCK STRUCTURE HANDLES THE TERMINAL I/O FOR THE
        PROGRAM  */


       ON ENDFILE(SYSIN) BEGIN;
            DISPLAY(' ');
            DISPLAY( ' ');
            DISPLAY('DO YOU WANT TO PROCESS ANY RECORDS?');
            DISPLAY(' ');
            DIS1:DISPLAY('TYPE IN YES OR NO IN QUOTES');
            DISPLAY(' ');
            DISPLAY(' ') REPLY(BUFFER);
            ON ERROR CALL ERROR(DIS1);
            GET STRING(BUFFER) LIST(ANSWER);
            IF ANSWER='NO' THEN EXIT;
       IF ANSWER¬='YES' THEN DO;
            DISPLAY('YOU DIDNT SAY YES OR NO, WHAT THE HELL DO'||
            ' YOU WANT????');
            GO TO DIS1;
       END;
       DISPLAY('INDICATE WHAT YOU WANT BY TYPING IN ONE OF THE'||
         ' FOLLOWING:');


/*  THE FOLLOWING GROUPS ARE USED TO INSERT NEW RECORDS,
   DELETE RECORDS, AND CHANGE RECORDS WITHIN A SUFRING   */


       DO WHILE(BUFFER¬='');
       DISPLAY(' ');
       DIS2:DISPLAY('INSERT,DELETE,CHANGE,LOCATE,LISTING OR QUIT'
            ||' IN QUOTES');
       DISPLAY(' ');
       DISPLAY(' ') REPLY(BUFFER);
       ON ERROR CALL ERROR(DIS2);
       GET STRING(BUFFER) LIST(ANSWER);
       IF ANSWER ='INSERT'|ANSWER ='DELETE'|ANSWER ='CHANGE'
            |ANSWER='LOCATE'|ANSWER ='LISTING'|ANSWER ='QUIT'
       THEN DO;
       IF ANSWER='INSERT' THEN DO;
            DIS3:DISPLAY('INDICATE WHAT YOU WANT CHANGED BY'||

            'TYPING IN ONE OF THE FOLLOWING:');
            DISPLAY('LAST,FIRST,OCCUPATION,CITY, AGE IN QUOTES');
            DISPLAY(' ');
            DISPLAY(' ') REPLY(BUFFER):
            ON ERROR CALL ERROR(DIS3);
            GET STRING (BUFFER) LIST(NLAST,NFIRST,NOCC,NCITY,
                 NAGE);
            CALL BUILD(NLAST);
       END;
       IF ANSWER='DELETE' THEN DO;
            DIS4:DISPLAY('INDICATE WHICH RECORD IS TO BE'||
            'DELETED BY TYPING IN THE LASTNAME AND THE FIRST'
            ||'NAME IN QUOTES')REPLY(BUFFER);
            ON ERROR CALL ERROR(DIS4);
            GET STRING(BUFFER) LIST(NLAST,NFIRST);
            CALL FIND(NLAST,NFIRST);
            IF POSITION=0 THEN
                 IF FRONT->NEXT_RECORD=NULL & BACK= ALPHA_PTR
                 THEN DO;
                      LIST_PTR=NULL;
                      FREE RECORD;
                 END;
                 ELSE DO;
                      BACK->NEXT_RECORD=FRONT->NEXT_RECORD;
                      FREE RECORD;
                 END;
       END;
       IF ANSWER='LISTING' THEN DO;
            LISTING=1;
            CALL PRINT;
            LISTING=0;
       END;
       IF ANSWER='LOCATE' THEN DO;
            DIS10:DISPLAY('INDICATE WHOSE RECORD YOU'||
            'WANT LOCATED BY TYPING IN THE LAST AND '||
            'FIRST NAME IN QUOTES')REPLY(BUFFER);
            ON ERROR CALL ERROR(DIS10);
            GET STRING(BUFFER) LIST(NLAST,NFIRST);
            CALL FIND(NLAST,NFIRST);
            IF POSITION=0 THEN DISPLAY(LAST||FIRST||OCCUPATION||
                 CITY||AGE);
       END;
       IF ANSWER='CHANGE' THEN DO;
            DIS5:DISPLAY('CHANGE WHAT?');
            DISPLAY('INDICATE EITHER NAME,CITY,'||
            'OCCUPATION,OR AGE IN QUOTES')REPLY(BUFFER);
       ON ERROR CALL ERROR(DIS5);
            GET STRING (BUFFER) LIST(ANSWER);
```

```
          IF ANSWER='NAME' THEN DO;
          DIS6:DISPLAY('TYPE IN THE FOLLOWING ITEMS IN '||
            'QUOTES :OLD_LAST,OLD_FIRST,NEW_LAST,NEW_FI'||
                 'RST')REPLY (BUFFER);
          ON ERROR CALL ERROR(DIS6);
               GET STRING(BUFFER) LIST(OLD_LAST,OLD_FIRST,
                   NLAST,NFIRST);
               CALL FIND(OLD_LAST,OLD_FIRST);
          IF POSITION=0 THEN DO;
                         BACK->NEXT_RECORD=FRONT->NEXT_RECORD;
                         NOCC=OCCUPATION;
                         NCITY=CITY;
                         NAGE=AGE;
                         FREE RECORD;
                         CALL BUILD(NLAST);
                    END;
          END;
          IF ANSWER ='CITY' THEN DO;
          DIS7:DISPLAY('TYPE IN LAST, FIRST AND THE NEW CITY'||
          'IN QUOTES')REPLY(BUFFER);
                    ON ERROR CALL ERROR(DIS7);
               GET STRING(BUFFER) LIST(OLD_LAST,OLD_FIRST,NCITY
                    );
               CALL FIND(OLD_LAST,OLD_FIRST);
               IF POSITION=0 THEN CITY=NCITY;
          END;
          IF ANSWER='OCCUPATION' THEN DO;
               DIS8:DISPLAY('TYPE IN LAST,FIRST AND NEW'||
               'OCCUPATION IN QUOTES')REPLY (BUFFER);
               ON ERROR CALL ERROR(DIS8);
               GET STRING(BUFFER) LIST(OLD_LAST,OLD_FIRST,
                  NOCC);
               CALL FIND (OLD_LAST,OLD_FIRST);
               IF POSITION=0 THEN OCCUPATION=NOCC;
               END;
          IF ANSWER='AGE' THEN DO;
               DIS9:DISPLAY('TYPE IN LAST,FIRST AND NEW AGE'||
               'IN QUOTES')REPLY(BUFFER);
               ON ERROR CALL ERROR(DIS9);
               GET STRING(BUFFER) LIST(OLD_LAST,OLD_FIRST,NAGE)
                    ;
               CALL FIND(OLD_LAST,OLD_FIRST);
               IF POSITION=0 THEN AGE=NAGE;
          END;
          IF ANSWER='NAME'|ANSWER='CITY'|ANSWER='AGE'|
            ANSWER='OCCUPATION' THEN DO;
            DISPLAY('THE INDICATED RECORD HAS BEEN CHANGED '
                 ||'TO READ:');
            DISPLAY(LAST||FIRST||OCCUPATION||CITY||AGE);
          END;
          ELSE DO;
            DISPLAY('I CANT FIGURE OUT WHAT YOU WANT '||
            'CHANGED; I CANT ONLY ASSUME THAT:');
            CALL ERROR(DIS5);
          END;
     END;
     IF ANSWER='QUIT' THEN DO;
          DISPLAY('YOU HAVE INDICATED THAT NO MORE WORK IS TO '
               ||'BE DONE; THEREFORE I WILL PUT A CURRENT LIST'
               ||'ING IN SYSPRINT BEFORE EXITING:');
          CALL PRINT;
          EXIT;
     END;
     END;
     ELSE DO;
          DISPLAY('I CANT FIGURE OUT WHAT IT IS YOU WANT DONE'
           ||'; ICAN ONLY ASSUME THAT:');
          CALL ERROR(DIS2);
     END;
ND;
ND;


THIS GROUP OF 8 STATEMENTS IS THE MAIN PROGRAM WHICH
OBTAINS THE DATA FROM THE SYSIN FILE AND CALLS THE
```

```
          BUILD PROCEDURE TO BUILD A SUBRING STRUCTURE (DATA
          RECORDS)  */


         DO I=1 TO 26;
              ALPHA_ARRAY(I)=NULL;
         END;
         FIRST_LTR=NULL;
         DO WHILE('1'B);
              GET LIST(NLAST,NFIRST,NOCC,NCITY,NAGE);
              CALL BUILD (NLAST);
         END;


 /* THE FOLLOWING PROCEDURE ALLOWS FOR CORRECTION OF TERMINAL
         INPUT ERRORS */


ERROR:PROC (LABEL);
         DCL LABEL LABEL;
         DISPLAY(' ');
         DISPLAY('THERE IS AN ERROR IN THE INPUT');
         DISPLAY('THE LAST INPUT FROM THE TERMINAL WAS:');
         DISPLAY(' ');
         DISPLAY(BUFFER);
         DISPLAY(' ');
         DISPLAY('CHECK IT THEN RE-INPUT THE CORRECT DATA AS FOLLOWS:');
         GO TO LABEL;
END ERROR;


       /* THIS FUNCTION CALLS PROCEDURES WHICH CONSTRUCT (1) A
          RING WHICH HAS THE FIRST LETTER OF A PERSON'S LAST NAME
          AND (2) A SUBRING WHICH HAS DATA ITEMS: LAST NAME, FIRST
          NAME, OCCUPATION,CITY,AGE */


 BUILD:  PROC(NLAST) ;
              DCL NLAST CHAR(10);
         IF FIRST_LTR=NULL THEN DO;
              ALPHA_PTR=BUILD_ALPHA(FIRST_LTR);
         CALL BUILD_REC (ALPHA_PTR,FRONT);
         RETURN;
         END;
         ELSE DO;
              ALPHA_PTR=FIRST_LTR;
              DO WHILE('1'B);
                   IF SUBSTR(NLAST,1,1)¬=ALPHA_PTR->LTR THEN DO;
                        ALPHA_PTR=ALPHA_PTR->NEXT_LTR;
                        IF ALPHA_PTR=FIRST_LTR THEN DO;
                             ALPHA_PTR=BUILD_ALPHA(FIRST_LTR);
                             CALL BUILD_REC(ALPHA_PTR,FRONT);
                             RETURN;
                        END;
                   END;
                   ELSE DO;
                        FRONT=LOOK_UP (NLAST,NFIRST);
                        IF POSITION¬=0 THEN
                             CALL BUILD_REC (ALPHA_PTR,FRONT);
                        RETURN;
                   END;
              END;
         RETURN;
 END BUILD;


       /* THE FOLLOWING PROCEDURE BUILDS A SUBRING, UNDER THE FIRST
          LETTER OF A PERSON'S LAST NAME, WHICH CONTAINS DATA ITEMS:
          LAST NAME, FIRST NAME, OCCUPATION, CITY, AGE */


 BUILD_REC:     PROC (ALPHA_PTR,FRONT);
         DCL (ALPHA_PTR,FRONT) PTR;
         ALLOCATE RECORD;
         LAST=NLAST;
         FIRST=NFIRST;
```

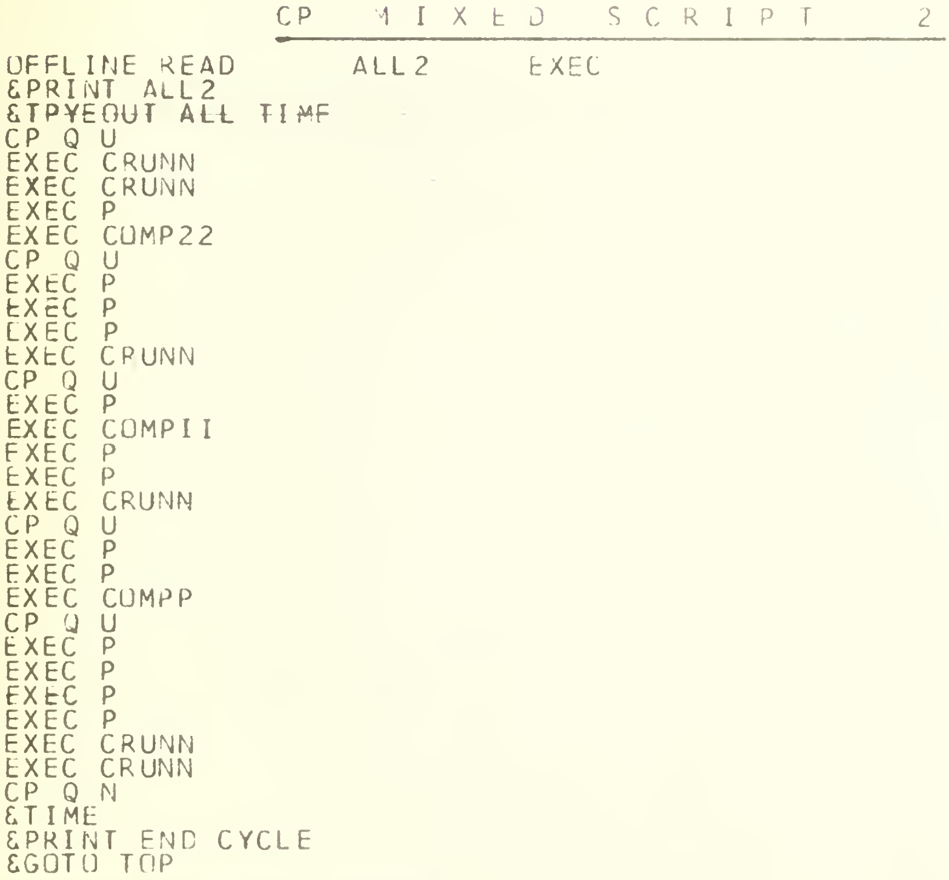
```
        OCCUPATION=NOCC;
        CITY=NCITY;
        AGE=NAGE;
        IF ALPHA_PTR=FRONT THEN
             IF LIST_PTR=NULL THEN DO;
                  NEXT_RECORD=NULL;
                  LIST_PTR=NEW_RECORD;
                  RETURN;
             END;
             ELSE DO;
                  NEXT_RECORD=LIST_PTR;
                  LIST_PTR=NEW_RECORD;
                  RETURN;
             END;
        ELSE DO;
             NEXT_RECORD=FRONT->NEXT_RECORD;
             FRONT->NEXT_RECORD=NEW_RECORD;
             RETURN;
        END;
END BUILD_REC;


      /* THE FOLLOWING PROCEDURE LOOKS TO SEE WHERE DATA ITEMS, LAST
         LAST AND FIRST NAME OF A RECORD, ARE TO BE INSERTED IN THE
         SUBRING    */


LOOK_UP:  PROC (NLAST,NFIRST) PTR;
        DCL (NLAST,NFIRST) CHAR(10);
        FRONT=ALPHA_PTR->LIST_PTR;
        BACK=ALPHA_PTR;
        POSITION =1;
        DO WHILE (FRONT¬=NULL);
             IF NLAST||NFIRST>FRONT->LAST||FRONT->FIRST THEN DO;
                  BACK=FRONT;
                  FRONT=FRONT->NEXT_RECORD;
             END;
             ELSE IF NLAST||NFIRST=FRONT->LAST||FRONT->FIRST
                       THEN DO;
                            POSITION=0;
                            RETURN(FRONT);
                       END;
                       ELSE RETURN(BACK);
        END;
        RETURN(BACK);
END LOOK_UP;


      /* THE FOLLOWING PROCEDURE BUILDS THE RING WHICH CONTAINS THE
         LETTERS OF THE ALPHABET. THE LETTERS OF THIS RING ARE THEN
         USED AS ENTRY POINTS FOR THE INSERTION OF RECORDS CONTAINING
         THE FIRST LETTER OF A PERSON'S LAST NAME CORRESPONDING
         TO THE LETTER OF THE ALPHABET  IN THE RING */


BUILD_ALPHA:   PROC (FIRST_LTR) PTR;
        DCL FIRST_LTR PTR;
        DCL TEMP2 FIXED BIN(15);
        ALLOCATE ALPHA;
        TEMP2=INDEX(ALPHABET,SUBSTR(NLAST,1,1));
        ALPHA_ARRAY(TEMP2)=ALPHA_PTR;
        LTR=SUBSTR(NLAST,1,1);
        LIST_PTR=NULL;
        FRONT=ALPHA_PTR;
        IF FIRST_LTR=NULL THEN DO;
             FIRST_LTR=ALPHA_PTR;
             NEXT_LTR=FIRST_LTR;
        END;
        ELSE DO;
```

```
              NEXT_LTR=FIRST_LTR->NEXT_LTR;
              FIRST_LTR->NEXT_LTR=ALPHA_PTR;
         END;
         RETURN (ALPHA_PTR);
 END BUILD_ALPHA;


       /* THE FOLLOWING PROCEDURE PRINTS OUT A LISTING OF THE ENTIRE
          STRUCTURE OR A LISTING OF THE SYSPRINT FILE  */


 PRINT:  PROC;
         DCL (TEMP) PTR;
        IF LISTING=0 THEN OPEN FILE (SYSPRINT);
         DO I=1 TO 26;
              IF ALPHA_ARRAY(I)¬=NULL THEN DO;
                   TEMP=ALPHA_ARRAY(I);
                   NEW_RECORD=TEMP->LIST_PTR;
                   DO WHILE(NEW_RECORD¬=NULL);
                        IF LISTING=0 THEN PUT EDIT(LAST,FIRST,OCCUPATION,
                        CITY,AGE)(SKIP,A(10),A(10),A(10),A(10),A(3));
                   ELSE DISPLAY(LAST||FIRST||OCCUPATION||CITY||AGE);
                         NEW_RECORD=NEW_RECORD->NEXT_RECORD;
                   END;
              END;
         END;
         RETURN;
 END PRINT;


       /* THE FOLLOWING PROCEDURE LOCATES THE LETTER OF THE ALPHABET
          CORRESPONDING TO THE FIRST LETTER OF A PERSON'S LAST
          NAME AND SEARCHES THROUGH THE SUBRING FOR THE LAST
          NAME AND FIRST NAME OF THE RECORD DESIRED  */


FIND:PROC(NLAST,NFIRST);
         DCL(NLAST,NFIRST) CHAR(10);
         ALPHA_PTR=FIRST_LTR;
         IF FIRST_LTR=NEXT_LTR THEN IF SUBSTR(NLAST,1,1)¬=LTR
              THEN DISPLAY('RECORD NOT IN FILE, YOU BLEW IT     ');
              ELSE DO;
                   NEW_RECORD=LOOK_UP(NLAST,NFIRST);
                   IF POSITION¬=0 THEN DISPLAY('RECORD NOT IN FILE,'||
                   'YOU BLEW IT');
                   RETURN;
              END;
         ELSE IF SUBSTR(NLAST,1,1)=LTR THEN DO;
                   NEW_RECORD=LOOK_UP(NLAST,NFIRST);
                   IF POSITION¬=0 THEN DISPLAY('RECORD NOT IN FILE,'||
                   'YOU BLEW IT');
                   RETURN;
         END;
              ELSE DO;
                   ALPHA_PTR=ALPHA_PTR->NEXT_LTR;
                   DO WHILE(ALPHA_PTR¬=FIRST_LTR);
                        IF SUBSTR(NLAST,1,1)=LTR THEN DO;
                             NEW_RECORD=LOOK_UP(NLAST,NFIRST);
                             IF POSITION¬=0 THEN DISPLAY('RECORD NOT'||
                             'IN FILE, YOU BLEW IT');
                             RETURN;
                        END;
                        ELSE ALPHA_PTR=ALPHA_PTR->NEXT_LTR;
                   END;
                   IF ALPHA_PTR=FIRST_LTR THEN
                        DISPLAY('RECORD NOT IN FILE, YOU BLEW IT     ');
              END;
END FIND;
 END PROJECT;
```



CP MIXED SCRIPT 1

```
OFFLINE READ       ALL1      EXEC
&PRINT ALL1
&TPYEOUT ALL TIME
CP Q U
EXEC P
EXEC COMPP
EXEC P
EXEC P
EXEC P
EXEC P
EXEC CRUNN
CP Q U
EXEC COMPII
EXEC P
EXEC P
EXEC CRUNN
CP Q U
EXEC P
EXEC P
EXEC COMP22
CP Q U
EXEC P
EXEC P
EXEC P
EXEC CRUNN
CP Q U
EXEC P
EXEC CRUNN
EXEC CRUNN
CP Q N
&TIME
&PRINT ENC CYCLE
&GOTU TOP
```



CP MIXED SCRIPT 2

```
OFFLINE READ       ALL2      EXEC
&PRINT ALL2
&TPYEOUT ALL TIME
CP Q U
EXEC CRUNN
EXEC CRUNN
EXEC P
EXEC COMP22
CP Q U
EXEC P
EXEC P
EXEC P
EXEC CRUNN
CP Q U
EXEC P
EXEC COMPII
EXEC P
EXEC P
EXEC CRUNN
CP Q U
EXEC P
EXEC P
EXEC COMPP
CP Q U
EXEC P
EXEC P
EXEC P
EXEC P
EXEC CRUNN
EXEC CRUNN
CP Q N
&TIME
&PRINT END CYCLE
&GOTO TOP
```

CP MIXED SCRIPT 3

```
OFFLINE READ       ALL3     EXEC
&PRINT ALL3
&TPYEOUT ALL TIME
CP Q U
EXEC P
EXEC P
EXEC CRUNN
CP Q U
EXEC COMPII
EXEC P
EXEC P
EXEC CRUNN
EXEC CRUNN
CP Q U
EXEC P
EXEC COMPP
CP Q U
EXEC P
EXEC P
EXEC P
EXEC P
EXEC CRUNN
EXEC P
CP Q U
EXEC CRUNN
EXEC COMP22
EXEC P
EXEC P
EXEC P
EXEC CRUNN
CP Q N
&TIME
&PRINT END CYCLE
&GOTO TOP
```

CP MIXED SCRIPT FOR MEASURING LOAD UNDER NORMAL OPERATING CONDITIONS

```
CP67USERID  0770         06/08/71    14.20.27    ********************************

OFFLINE READ       MIX       EXEC
&TYPEOUT OFF
&PRINT >>>>>>>> <<<<<<<< >>>>>>>> <<<<<<<< >>>>>>>> <<<<<<<< >>>>>>>> <<<<<<<< *
&PRINT >>>>>>>> <<<<<<<< >>>>>>>> <<<<<<<<>>>>>>>> <<<<<<<< >>>>>>>> <<<<<<<<***
&PRINT START MIX BENCHMARK FOR PROBING SYSTEM LOAD
BLIP
&TIME
&PRINT ======== ======== ======== ======== ========
CP Q U
CP Q N
&PRINT ======== ======== ======== ======== ========
EXEC P
&PRINT ======== ======== ======== ======== ========
EXEC COMPP
&PRINT ======== ======== ======== ======== ========
EXEC CRUNN
&PRINT ======== ======== ======== ======== ========
CP Q U
CP Q N
&PRINT ======== ======== ======== ======== ========
EXEC COMPII
&PRINT ======== ======== ======== ======== ========
EXEC PG
&PRINT ======== ======== ======== ======== ========
EXEC COMP22
&PRINT ======== ======== ======== ======== ========
EXEC P
&PRINT ======== ======== ======== ======== ========
CP Q U
CP Q N
&PRINT ======== ======== ======== ======== ========
&TIME
&PRINT END MIX BENCHMARK
&PRINT >>>>>>>> <<<<<<<< >>>>>>>> <<<<<<<<>>>>>>>> <<<<<<<< >>>>>>>> <<<<<<<<***
&PRINT >>>>>>>> <<<<<<<< >>>>>>>> <<<<<<<<>>>>>>>> <<<<<<<< >>>>>>>> <<<<<<<<***
&PRINT
&PRINT
&PRINT
&PRINT THIS TERMINAL IS NOW AVAILABLE FOR YOUR USE...
&PRINT
&PRINT PLEASE TEAR OFF COPY AND LEAVE IT NEXT TO TERMINAL...
&PRINT TERMINAL WILL LOG ITSELF OFF.......THANK YOU.
&PRINT
&PRINT
&PRINT
CP LOG
```

EXEC ROUTINES FOR MIXED SCRIPTS

LAST LETTER DUPLICATED INDICATES NO LOOPING, OTHERWISE ROUTINE IS THE SAME, EXCEPT FOR PRINT OUT AND TIME DISPLAY

ALIAS EDIT

```
OFFLINE READ      P        EXEC
&TYPEOUT ALL TIME
&BEGSTACK
L /50/
N 10
TOP
FILE
&END STACK
EDIT LOOP FORTRAN
&TIME
```

ALIAS FORTEX

```
OFFLINE READ      CRUNN    EXEC
&TYPEOUT OFF TIME
&PRINT START CRUNN  *********
&TIME
LOAD FTN (XEQ)
&TIME
&PRINT CRUNN  COMPLETE ***************
```

ALIAS FORTRAN

```
OFFLINE READ      COMPII   EXEC
&TYPEOUT OFF
&PRINT START COMPII*************
&TIME
FORTRAN LOOP
&TIME
&PRINT **COMPI COMPLFTE**
```

ALIAS PLISM

```
OFFLINE READ      COMP22   EXEC
&TYPECUT OFF
&PRINT START COMP2*********
&TIME
PLI HAI3
&TIME
&PRINT **COMP2 COMPLETE**
```

ALIAS PLILG

```
OFFLINE READ      COMPP    EXEC
&TYPEOUT OFF
&PRINT START COMP**********
&TIME
PLI FINK
&TIME
&PRINT **COMP COMPLETE**
```

ALIAS PAGE

```
OFFLINE READ      PG       EXEC
&TYPEOUT OFF
&PRINT START PAGING***********
&TIME
LOAD PAGE (XEQ)
&TIME
&PRINT PAGING COMPLETE*********
```

TSS PROCDEF   BELANGER'S COPY   MASTER COPY

```
P67USERID  0770
FFLINE READ TSS PLI
 LOGON GREGERIS

PROCDEF P                                                                   PR001660
DISPLAY 'START TSS EDIT'                                                    PR001670
CLOCK                                                                       PR001680
DEFAULT SYSINX=E                                                            PR001690
EDIT SOURCE.LOOP                                                            PR001700
 _LOCATE 0,LAST,STRING='50'                                                 PR001710
LIST 310                                                                    PR001720
LIST 100                                                                    PR001730
END                                                                         PR001740
DEFAULT SYSINX=G                                                            PR001750
CLOCK                                                                       PR001760
DISPLAY 'END EDIT'                                                          PR001770
_END                                                                        PR001780

PROCDEF CRUNN                                                               PR000110
DISPLAY 'START CRUNN'                                                       PR000120
CLOCK                                                                       PR000130
CALL FTN                                                                    PR000140
CLOCK                                                                       PR000150
DISPLAY 'END CRUNN'                                                         PR000160
_END                                                                        PR000170

PROCDEF COMPII                                                              PR000620
DISPLAY 'START COMPII'                                                      PR000630
CLOCK                                                                       PR000640
ERASE USERLIB (LOOP)                                                        PR000650
FTN LOOP,Y                                                                  PR000660
CLOCK                                                                       PR000670
DISPLAY 'END COMPII'                                                        PR000680
_END                                                                        PR000690

PROCDEF COMP22
DISPLAY 'START COMP22'                                                      PR000040
CLOCK                                                                       PR000050
PLI HAI3,Y                                                                  PR000060
CLOCK                                                                       PR000070
DISPLAY 'END COMP22'                                                        PR000080
_END                                                                        PR000090

PROCDEF COMPP                                                               PR000540
DISPLAY 'START COMPP'                                                       PR000550
CLOCK                                                                       PR000560
PLI FINK,Y                                                                  PR000570
CLOCK                                                                       PR000580
DISPLAY 'END COMPP'                                                         PR000590
_END                                                                        PR000600

PROCDEF PG                                                                  PR001430
DISPLAY 'START PAGING'                                                      PR001440
CLOCK                                                                       PR001450
CALL PAGE                                                                   PR001460
CLOCK                                                                       PR001470
DISPLAY 'END PAGING'                                                        PR001480
_END                                                                        PR001490
```

```
PROCDEF ALL1
DISPLAY 'START ALL1'
CLOCK
AID 5
P
COMPP
P
P
P
P
CRUNN
AID 5
COMPII
P
P
CRUNN
AID 5
P
P
COMP22
AID 5
P
P
P
CRUNN
AID 5
P
CRUNN
CRUNN
AID 1
CLOCK
DISPLAY 'END CYCLE'
ALL1
_END

PROCDEF ALL2
DISPLAY 'START ALL2'
CLOCK
AID 5
CRUNN
CRUNN
P
COMP22
AID 5
P
P
P
CRUNN
AID 5
P
COMPII
P
P
CRUNN
AID 5
P
P
COMPP
AID 5
P
P
P
P
CRUNN
CRUNN
AID 1
CLOCK
DISPLAY 'END CYCLE'
ALL2
_END
```

```
ROCDEF ALL3
ISPLAY 'START ALL3'
LOCK
ID 5


RUNN
ID 5
OMPII


RUNN
RUNN
ID 5

OMPP
ID 5




RUNN

ID 5
RUNN
OMP22



RUNN
ID 1
LOCK
ISPLAY 'END CYCLE'
LL3
END

ROCDEF MIX
ISPLAY 'START STAND ALONE MIX'
LOCK
ID 5
ID 1

OMPP
RUNN
OMPII
OMP22
G
LOCK
ISPLAY 'END MIX'
END
```

```
PROCDEF ALL4
DISPLAY 'START ALL4'
CLOCK
AID 5
P
COMPP
P
P
P
P
CRUNN
AID 5
COMPII
P
P
CRUNN
AID 5
P
P
PG
AID 5
P
P
P
CRUNN
AID 5
P
CRUNN
CRUNN
AID 1
CLOCK
DISPLAY 'END CYCLE'
ALL4
_END
 LOGOFF
```

MTS SCRIPTS

```
     EDIT SCRIPT

$$RUN *TIME
$$RUN *ED;SCARDS=EAS:EDITS
$$RUN *TIME
$CONTINUE WITH EAS:EDITOR
        FILE EAS:EDITS CONTAINS
XEC $EDT
EDIT EAS:LOOP
TOP: SCAN@A *F 26 '50'
L *F
+3
L *L
L *F
P 10 20
STOP
$EDT


     FORTRAN SCRIPT

$$RUN *TIME
$$RUN *FORTRAN;SCARDS=EAS:FORTRAN PAR=NOSOURCE,NOMAP,NOLOAD
$$RUN *TIME
$$CONTINUE WITH EAS:FORCOMP


     FORTEX SCRIPT

$$RUN *TIME
$$RUN EAS:FORTEX
$$RUN *TIME
$$CONTINUE WITH EAS:FORTX


     PAGE SCRIPT

$$RUN *TIME
$$RUN EAS:PAGE
$$RUN *TIME
$$CONTINUE WITH EAS:PAGER


     PLISM SCRIPT

$$RUN *TIME
$$RUN *PL1;SCARDS=EAS:PLISM PAR=NS,NLD,NS2,NOL
$$RUN *TIME
$$CONTINUE WITH EAS:PLILIT


     PLILG SCRIPT

$$RUN *TIME
$$RUN *PL1;SCARDS=EAS:PLILG PAR=NS,NLD,NS2,NOL
$$RUN *TIME
$$CONTINUE WITH EAS:PLIBG
```

Appendix B

BATCH BENCHMARKING PROGRAMS

Seventeen FORTRAN and assembler jobs were collected as a batch benchmarking jobstream. The jobs contained one to seven subroutines, required region sizes of 58K bytes to 300K bytes, produced one to fourteen pages of output and required 5 seconds to 360 seconds of CPU time. A summary of the jobs in the batchmark is shown in Tables B1 and B2. A summary of the CPU times required is given in Table B3.

The benchmark programs were arranged in three benchmarks called Jobstreams A, B and C. Jobstreams A and B contained 15 programs SYS001 through SYS015, whereas Jobstream C contained two extra programs, SYS13A and SYS14A. Jobstream A and B included compile, link and go steps with program listings and no listings, respectively. In both cases, the writer was started, then the reader and initiator were started together. For Jobstream C, the programs were precompiled on a disk so that only execution steps were performed. All the JCL (Job Control Language) and data decks were read before the initiation was started.

The most significant data collected was the time from the start of the card reader (or the initiator in the case of Jobstream C) until the last line was printed. In some cases, the time from the start of the third job being initiated until the time for the third-last job finishing was also recorded. Also, the time in which at least two jobs were multiprogramming was also recorded.

A complete listing of the batch benchmarking programs can be obtained by writing to the author or a copy of the jobstreams can be obtained by sending a blank magnetic tape.

Table B1: Batch Benchmarking Jobstream Characteristics

	No. of subroutines		Execution			
Job Name	FORTRAN	ASSEMBLER	Region-k	pages of output	Input data	Total CPU ~ sec.
SYS001	7	-	58	1	No	10
SYS002	6	-	100	14	Yes	12
SYS003	2	-	58	5	No	2
SYS004	8	-	82	5	Yes	34
SYS005	5	-	58	2	Yes	6
SYS006	1	1	58	12	No	7
SYS007	4	-	110	4	Yes	9
SYS008	3	1	58	2	No	6
SYS009	7	-	58	9	Yes	13
SYS010	2	-	58	8	No	5
SYS011	2	-	58	1	No	6
SYS012	1	1	58	12	No	7
SYS013	3	-	140	3	Yes	359
SYS014	1	-	300	1	No	266
SYS015	1	-	300	1	No	266
SYS13A	3	-	140	3	Yes	359
SYS14A	1	-	300	1	No	266

Table B2: Jobstream Summary by Region and CPU Time

Jobstream	No. of jobs for region size						No. of jobs with total CPU time ~ sec							
	58K	83K	100K	110K	140K	300K	≤2	≤5	≤10	≤15	≤30	≤60	≤300	≤360
A	9	1	1	1	1	2	1	1	7	2	-	1	2	1
B	9	1	1	1	1	2	1	1	7	2	-	1	2	1
C	9	1	1	1	2	3	4	6	1	-	1	-	3	2

Table B3: Jobstream C: Execution and Region Used

Job Name	Region k	OS/MVT CPU Time (sec.)
SYS001	58	6.63
SYS002	100	4.29
SYS003	58	0.42
SYS004	82	19.51
SYS005	58	0.75
SYS006	58	2.56
SYS007	110	2.07
SYS008	58	0.30
SYS009	58	4.13
SYS010	58	2.20
SYS011	58	0.11
SYS012	58	2.53
SYS013	140	342.94
SYS13A	140	345.00
SYS014	300	261.46
SYS14A	300	257.82
SYS015	300	255.44

Appendix C

CP INTERMEDIATE TERMINAL RESULTS

This appendix presents the intermediate results from the CP terminal tests that were used to prepare the graphs in Section 6, especially Subsection 6.2. These intermediate results are presented here for easy reference or further analysis that might be desirable.

Table C1 presents the average response time at each terminal for the CP tests. This table was prepared by averaging all response times that were obtained from the terminal printout for each individual terminal. For example, for a benchmark test running four EDIT scripts, there should be four mean terminal response times. Runs R21 to R25 are an exception since they present only the mean response time for a script (averaged overall terminals running that script).

Table C2 presents the CP mean response times for each script which were obtained by averaging the response times at all terminals running the same script. The mean response time was used in determining the calculated throughput as shown in Table C3.

Tables C4 and C5 show the terminal and script measured throughputs, respectively. The measured throughput was determined by counting the number of job completions and dividing the run duration.

Table C6 presents the minimum, or stand-alone, CP response times for each script as determined by one of several methods. The minimum response times were used in calculating the effective progress rate as shown in Table C7. The total effective progress rate is particularily interesting since it provides a direct comparison with a serial processing computer, as discussed in Subsection 6.2.4.

Table C8 presents two of the software monitor results for all CP runs, namely, the percentage of CPU time in the problem state and the page reading rates. Table C9 presents a more detailed version of the results from the software monitor for Test 3 (Runs R31 to R37).

Table C10 presents the individual terminal response times that were used to compare the CP performances when operating with one, two and three core boxes. Unfortunately the run with three core boxes was so short that it is considered unreliable and was not included in the analysis and results presented in Section 6. The results for the runs with one and two core boxes are used to compare the CP performance with TSS which had three core boxes.

Table C1 CP - Average Response Time at Each Terminal (in minutes:seconds)

RUN NUMBER	CP LOAD FACTOR	RESPONSE TIME						NO. EDIT	NO. PAGE	NO. FORTEX	NO. PLISM	NO. PLILG	NO. FORTRAN
		EDIT	PAGE	FORTEX	PLISM	PLILG	FORTRAN						
21	32						:15	8	0	3	0	0	1
22	32							10	0	2	0	0	1
23	48					4:48	:18	12	0	3	0	1	1
24	60					6:24	:48	14	0	3	0	1	3
25	64					5:36	:53	15	0	4	1	1	1
R31	110	1:38 1:00 :37 :26			8:29 8:21 8:44	22:31 22:54 22:59 21:43	2:46 2:45 2:44 2:47 2:40 2:39 2:45	4	0	6	3	4	7
R32	86	:49 1:05 :56 1:15 :52 :45 1:23 1:34 2:40 2:14 2:04 1:34			10:22 10:24 8:35	25:08 31:36	2:52 2:46 3:08 2:48 2:55	12	0	2	3	2	5
R33	130	:49 1:02 :50 1:15 1:03 :44 1:26 1:43 2:06 2:22			12:48 14:14 14:07	31:06 25:36	4:30 4:42 4:48 5:03 4:40	10	2	2	3	2	5

Table C1 (continued)

RUN NUMBER	CP LOAD FACTOR	RESPONSE TIME						NO. EDIT	NO. PAGE	NO. FORTEX	NO. PLISM	NO. PLILG	NO. FORTRAN
		EDIT	PAGE	FORTEX	PLISM	PLILG	FORTRAN						
R34	174	:45 :29 :51 :47 :38 :34 1:07 1:16			14:01 15:09 14:04	41:58 39:11	5:01 5:20 5:08 5:10 5:11	8	4	2	3	2	5
R35	218	:49 :43 :42 1:10 :55 :47			15:10 14:22 16:23		3:17 8:31 7:06 3:51 4:56	6	6	2	3	2	5
R41	66	1:02 1:02 1:06 :44 :54 1:00 :46 :52 1:09 :58 :40 :48 :51 :45		5:33 5:41 4:56 6:01 6:19	3:12	12:31	1:29	14	0	5	1	1	1
R42	68	1:00 :51 :57 1:00 :55 :50 :52 1:06 1:09 1:07 :57 :48 :41		5:12 5:04 5:08 5:07 4:56 5:06	3:38	11:26	1:16	13	0	6	1	1	1

Table C1 (continued)

RUN	CP LOAD	RESPONSE TIME						NO.	NO.	NO.	NO.	NO.	NO.
NUMBER	FACTOR	EDIT	PAGE	FORTEX	PLISM	PLILG	FORTRAN	EDIT	PAGE	FORTEX	PLISM	PLILG	FORTRAN
R43	86	1:36 1:47 1:16 1:21 1:35 1:44 1:41 1:44 1:29 1:45		7:54 7:29 7:35 8:01 7:46 7:26	7:01	14:59 14:53 15:35	7:50	10	0	6	1	4	1
R44	104	1:40 1:52 2:20 2:09 2:02 1:54 2:07		11:18 10:28 10:48 9:55 10:17 10:02	5:51	19:53 20:00 20:08 20:05 19:13 20:03	2:24	7	0	6	1	7	1
R45	146			15:27 14:00 14:36 13:47 13:00	9:40	18:54 28:16 28:14 22:13 28:07 28:15 28:19 28:46 28:54 28:45 28:23 26:48 27:06	3:22 3:49	0	0	5	1	14	2
R46	148			15:39 13:37 13:55 13:01		21:02	3:32 3:40	0	0	4	2	14	2

Table C1 (continued)

RUN NUMBER	CP LOAD FACTOR	RESPONSE TIME EDIT	PAGE	FORTEX	PLISM	PLILG	FORTRAN	NO. EDIT	NO. PAGE	NO. FORTEX	NO. PLISM	NO. PLILG	NO. FORTRAN
R47	68	1:08 1:11 1:17 1:21 1:05 :42 :42 1:03 :37 :33 1:08 1:20		5:12 5:19 5:06 5:14 5:25	4:14	11:20	1:20	13	0	6	1	1	1
R51	68	1:08 :43 :12 1:00 1:07 :46 :43 :51 :22 1:16 1:10 1:02 :49 1:46		4:24 5:11 7:10 5:45 5:17	7:09		1:32	15	0	5	1	1	1
R52	190			15:40 10:11 14:40 14:11	7:06		3:09	0	2	5	1	14	1
R53	174			10:08 10:05 6:59 7:01 11:10	12:38		3:10	0	1	5	1	15	1

Table Cl (continued)

RUN	CP LOAD	RESPONSE TIME						NO.	NO.	NO.	NO.	NO.	NO.
NUMBER	FACTOR	EDIT	PAGE	FORTEX	PLISM	PLILG	FORTRAN	EDIT	PAGE	FORTEX	PLISM	PLILG	FORTRAN
R54		1:03		5:14	5:25	10:57	1:14	15	0	5	1	1	1
	68	:37		5:28									
		:35		5:12									
		:59		5:39									
		1:08		4:53									
		:56											
		:26											
		:52											
		:34											
		1:09											
		:40											
		:53											
		:35											
		:46											
		:47											

Table C2: CP Mean Response Time for Each Script
(in minutes, Equation 8, section 4)

SCRIPT \ RUN	R21	R22	R23	R24	R25	R31	R32	R33	R34	R35	R41
EDIT	-	-	-	-	-	.92	1.43	1.33	.81	.85	.90
PAGE	-	-	-	-	-	-	-	-	-	-	-
FORTEX	-	-	-	-	-	-	-	-	-	-	5.70
PLISM	-	-	-	-	-	8.52	9.78	13.71	14.42	15.30	3.20
PLILG	-	-	4.8	6.4	5.6	22.53	28.37	28.35	40.58	-	12.52
FORTRAN	.25	-	.30	.80	.88	2.73	2.90	4.74	5.17	5.54	1.48
CP Load Factor	32	32	48	60	64	110	86	130	174	218	66
Combined Load Factor	28		40	46	55	104	68	86	104	128	

SCRIPT \ RUN	R42	R43	R44	R45	R46	R47	R51	R52	R53	R54	
EDIT	.94	1.60	2.01	-	-	1.01	.92	-	-	.80	
PAGE	-	-	-	-	-	-	-	-	-	-	
FORTEX	5.09	7.69	10.47	14.17	14.05	5.25	5.55	13.68	9.08	5.29	
PLISM	3.63	7.00	5.85	9.67	-	4.23	7.15	7.10	12.63	5.42	
PLILG	11.43	15.15	19.89	27.00	21.03	11.33	-	-	-	10.95	
FORTRAN	1.27	7.83	2.40	3.59	3.60	1.33	1.53	3.15	3.15	1.23	
CP Load Factor	68	86	104	146	148	68	68	190	174	68	

Table C3: CP Mean Calculated Throughput for Each Script (Equation 9, section 4)
(Similar to measured throughput/terminal/min)

RUN SCRIPT	R21	R22	R23	R24	R25	R31	R32	R33	R34	R35	R41
EDIT	-	-	-	-	-	1.09	.70	.75	1.23	1.18	1.11
PAGE	-	-	-	-	-	-	-	-	-	-	-
FORTEX	-	-	-	-	-	-	-	-	-	-	.18
PLISM	-	-	-	-	-	.12	.10	.07	.07	.06	.31
PLILG	-	-	.21	.156	.18	.04	.04	.04	.025	-	.08
FORTRAN	4.0	-	3.3	1.24	1.14	.37	.34	.21	.19	.18	.68
Sum	4.0	-	3.51	1.41	1.32	1.62	1.18	1.07	1.51	1.42	2.36
Total Calc. Throughput	4.0*	-	3.51*	2.91*	1.32*	7.47	10.48	8.84	11.04	8.16	17.51
Subtotal Throughput**	4.0		3.51	2.91	1.32	3.11	2.08	1.34	1.20	1.08	

RUN SCRIPT	R42	R43	R44	R45	R46	R47	R51	R52	R53	R54
EDIT	1.06	.62	.50	-	-	.99	1.09	-	-	1.25
PAGE	-	-	-	-	-	-	-	-	-	-
FORTEX	.20	.13	.10	.07	.07	.19	.18	.07	.11	.19
PLISM	.28	.14	.17	.10	-	.24	.14	.14	.08	.18
PLILG	.09	.07	.05	.04	.05	.09	-	-	-	.09
FORTRAN	.79	.13	.42	.28	.28	.75	.65	.32	.32	.81
Sum	2.42	1.09	1.24	.49	.40	2.35	2.13	.53	.51	2.52
Total Calc. Throughput	16.14	7.46	4.99	1.53	.89	13.91	16.95	.74	.95	20.78

*Unrealistically low because so few scripts had measured response times.

**Subtotal for FORTRAN, PLISM and PLILG scripts for comparison with TSS total throughput.

Table C4: CP Measured Terminal Throughput (in Job completions /min/terminal)

RUN SCRIPT	R31	R32	R33	R34	R35	R41	R42	R43	R44	R45	R46	R47	R51	R52	R53	R54
EDIT	.35	.362	.406	.425	.412	.468	.352	.375	.381	.075	-	.409	.460	-	-	.462
FORTRAN	.289	.275	.194	.176	.126	.583	.625	.560	.375	.208	-	.611	.666	.290	.214	.59
FORTEX	-	-	-	-	-	.172	.166	.125	.090	-	-	.133	.133	.0735	.085	.145
PLISM	.102	.099	.053	.066	.052	.250	.208	.187	.166	.125	-	.167	.111	.117	-	.18
PLILG	.032	.041	.060	.040	-	.055	.125	.062	.041	.042	-	.055	-	-	-	-
PAGE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CP Load Factor	110	86	130	174	218	66	68	86	104	144	152	68	68	190	174	68
Run Duration (minutes)	39	37	33	25	19	36	24	16	24	24	25	18	9	17	14	22

Table C5: CP Total Measured Throughput per Script (in Job completion/min)

RUN SCRIPT	R31	R32	R33	R34	R35	R41	R42	R43	R44	R45	R46	R47	R51	R52	R53	R54
EDIT	1.38	4.35	4.06	3.40	2.47	6.52	4.58	3.75	2.67	3.75	-	4.5	6.44	-	-	5.09
FORTRAN	2.02	1.65	.969	.88	.63	.583	.625	.56	.38	.416	-	.61	.67	.29	-	.59
FORTEX	-	-	-	-	-	.861	1.00	.75	.54	-	-	.67	.67	.29	.43	.73
PLISM	.307	.297	.212	.20	.157	.250	.21	.19	.17	.13	-	.167	.11	.12	-	.18
PLILG	.128	.082	.060	.08	-	.055	.13	.19	.25	.54	-	.055	-	-	-	-
PAGE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Throughput	3.84	6.38	5.30	4.56	3.26	8.27	6.55	5.44	4.01	4.84	0	6.00	7.89	.70 poor	.43	6.59
Subtotal throughput*	2.46	1.93	1.24	1.16	.79 ?											

*Subtotal for FORTRAN, PLISM, and PLILG scripts for comparison with TSS total throughputs

Table C6 : CP Minimum Response Times (Minutes)
(Used in Place of Stand-Alone Response Times in calculation of Effective Progress Rates.)

Source \ Script	EDIT	FORTRAN	FORTEX	PLISM	PLILG	PAGE
Haines & Porteifield's Thesis [2]	-	0.10	-	0.457	1.016	-
Terminal Probe Tests [14]	0.033 (2 sec)	0.116	0.38	0.483	1.15	6.27
Minimum during benchmark runs	0.5	0.88	3.6	2.1	8.76	-
Best Minimum Response Times	0.033	0.10	0.38	0.457	1.016	6.27
MTS (for comparison) [3]	2.84	0.18	0.28*	1.06	1.64	

*Scale by 100 from Hinson's thesis [3] because different multipliers were used.

Table C7 CP Effective Progress Rates †

SCRIPT \ RUN	R21	R22	R23	R24	R25	R31	R32	R33	R34	R35	R41
EDIT*	-	-	-	-	-	.036	.023	.025	.041	.039	.037
PAGE*	0	0	0	0	0	0	0	-	-	-	0
FORTEX	-	-	-	-	-	-	-	-	-	-	.067
PLISM	-	-	-	-	-	.054	.047	.033	.032	.03	.143
PLILG	-	-	.212	.159	.181	.045	.036	.036	.025	?	.081
FORTRAN	.40	-	.33	.125	.114	.037	.034	.021	.019	.018	.068
Sum+	.40	-	.542	.284	.295	.112	.14	.115	.117	.087	.396
Total Progress Rates+	.40	-	.54	.53	.30	.745	.659	.527	.569	.414	1.15
Above realistic	x		x	x	x	x	x	x	x	x	√

SCRIPT \ RUN	R42	R43	R44	R45	R46	R47	R51	R52	R53	R54
EDIT*	.035	.021	.016	0	0	.033	.036	0	0	.041
PAGE*	0	0	0	0	0	0	0	0	0	0
FORTEX	.075	.049	.036	.027	.027	.072	.068	.028	.042	.072
PLISM	.126	.065	.078	.047	-	.108	.064	.064	.063	.084
PLILG	.089	.067	.051	.038	.048	.09	-	-	-	.093
FORTRAN	.079	.013	.042	.028	.028	.075	.065	.032	.032	.081
Sum+	.404	.215	.223	.140	.103	.378	.233**	.124**	.137**	.371
Total Progress Rates+	1.20	.85	.805	.816	.836	1.13	1.01	.236**	.305**	1.23
Above realistic	√	√	√	√	?	√	?	x	x	√

†(minimum, or stand-alone, response time (Table C6) divided by mean response time for script i (Table C2)).

*Zero indicates no EDIT or PAGE scripts in benchmark.

**Unrealistically low because PLILG did not complete even once.

+Note the sums and the total progress rates are quite erroneous for runs R21 to R25 because response times for EDIT, FORTEX and PLISM are not available. Also the sums and total progress rates are low for runs R31 to R35 because the response time for FORTEX is not available. Runs R45, R46, R52 and R53 are ok because no EDIT scripts were run.

Table C8 CP Software Monitor Results Summary

Run	R11	R12	R13	R21	R22	R23	R24	R25	R31	R32
Average Problem Time %	51	32	64	82	86	57	46	51	16	10.5
Pages-Read (per minute)	10	23	6	9	6.5	14.9	18.6	14.8	26	32

Run	R33	R34	R35	R41	R42	R43	R44	R45	R46	R47
Average Problem Time %	7.5	8	7	39	42	38	30	25	24	36
Pages-Read (per minute)	34	32	32	19	23.5	17	20	22	21	20

Table C9: CP Software Monitor Results - Test 3

Memory	256k Bytes of Memory					512k	768k
Run	R31	R32	R33	R34	R35	R36	R37
a. CPU UTILIZATION	15.8 1.6	10.4 1.12	7.3 0.11	7.5 1.82	6.8 1.0	30.7 0.82	19.8 2.34
b. WAIT TIME	64.0 1.2	68.0 .9	72.4 0.36	72.8 1.76	73.4 1.60	49.4 2.46	63.1 3.21
c. CP TIME	15.2 0.14	16.6 .32	15.2 .36	14.5 .12	14.4 .50	15.7 1.47	13.5 1.01
d. OVERHEAD TIME	1.16	5.1 0.20	5.2 .04	5.1 .17	5.4 .10	4.1 .29	3.6 .12
e. PAGES READ/SEC	25.5 2.0	31.8 1.8	33.3 .51	31.5 2.0	31.8 1.05	10.9 2.33	10.2 53
f. PAGES SWAPPED/SEC	21.3 1.65	26.2 1.44	29.0 .52	28.6 2.19	28.5 .10	10.0 2.13	9.5 .53
g. PAGES STOLEN/SEC	20.8 1.70	26.3 2.00	29.1 .60	27.7 2.36	28.4 .65	2.83 1.23	3.6 .61
h. FORTRAN COMPILE RESPONSE TIME	2:44 :I8	2:56 :48	5:00 :24	5:46 :29	7:27 2:59	—	—
i. PLISM COMPILE RESPONSE TIME	8:40 :28	9:47 :71	15:19 :06	16:07 :66	15:10 0	—	—
j. PLILG COMPILE RESPONSE TIME	22:51 :12	30:25 :71	—	—	—	—	—
k. AVERAGE THROUGHPUT PLILG (COMPILES/MIN)	.043	.033	.027	.023	.011	.072	.048
l. AVERAGE THROUGHPUT PLISM (COMPILES/MIN)	.111	.098	.067	.062	—	.226	.147
m. AVERAGE THROUGHPUT FORTRAN (COMPILES/MIN)	.338	.319	.192	.174	.139	.584	.564
n. AVERAGE THROUGHPUT FORTEX (Blips per min)	.781	.743	.424	.360	.437	1.15	1.01

Notes:

1) With 1 core box (256k bytes), 38 pages are usable.

2) In rows a through d. the first number is a percent,and the second number is the standard deviation.

3) In rows e through g. the first number is the number of pages per second, and the second number is the standard deviation.

4) In rows h through j the first number is the response time in minutes and seconds, and the second number is the standard deviation in seconds.

5) In rows k through m average throughput is given in number of compiles per minute for each program type. In row n , one blip is equal to 2.4 seconds of CPU time.

Table C10 Individual Terminal Response Times For Determining Effect of Memory Size

Part a: FORTRAN (in minutes)

Run	R31	R36	R37
Compile #	One Core Box	Two Core Boxes	Three Core Boxes
1	2.37	1.41	2.03
2	2.52	1.55	2.00
3	2.24	1.25	1.09
4	2.25	1.35	1.45
5	2.41	1.28	2.08
6	2.56	1.36	1.34
7	2.30	1.43	2.08
8	2.28	1.23	1.50
9	2.48	1.43	1.12
10	2.34	1.50	1.51
11	2.27	1.43	2.08
12	3.15	1.28	1.42
13	1.21	1.45	
14	2.28	1.32	
15	2.59	1.29	
16	2.40	1.48	
17	2.46	1.27	
18	2.26	1.39	
19	2.37	1.43	
20	2.36	1.25	
Average (Minutes)	2.35	1.36	1.48

Part b: PLISM (in minutes)

1	9.18	3.55	5.56
2	8.55	4.03	7.43
3	8.38	3.51	
4	7.52	4.26	
5	9.10	4.22	
6	8.20	3.50	
7	8.13	4.18	
8	9.25	4.07	
9	8.49		
Average (Minutes)	8.45	4.06	6.34

Part c: PLILC (in minutes)

1	22.31	13.52	3.08
2	22.54	13.48	
3	22.59		
4	23.01		
Average (Minutes)	22.51	13.50	3.08*

*Very suspicious because the test run was so short.

Appendix D

TSS INTERMEDIATE RESULTS

This appendix presents the intermediate results from the TSS terminal tests that were used to prepare the graphs in Section 6.3. The intermediate results were obtained in the same way that the CP results were obtained.

Table D1 presents the TSS mean response times for all terminals running each of the scripts. Table D2 presents mean measured throughputs for each terminal in job completions per minute as determined by Equation 1 in Section 4.2. These results are the same as the mean measured throughputs per script but are not the same as the total throughputs per script as shown in Table D4. Table D3 is the equivalent of Table D2 except it contains the calculated throughputs as determined by Equation 9 in Section 4.2. The total calculated throughputs per script are shown in Table D5. The last lines of Tables D4 and D5 represent the total measured and calculated throughputs as determined by Equations 5 and 10, respectively.

Table D1: TSS Mean Response Times for each Script (minutes)

Run / Script	R21	R23	R24	R25	R31	R32	R33	R34	R35
FORTRAN	.30	.72	1.25	1.50	3.3	2.7	3.5	3.9	4.4
PLISM	–	–	–	–	15.8	13.1	17.5	19.0	21.0
PLILG	1.9	4.3	8.0	9.3	21.8	–	17.5	25.5	25.3
CP Load Factor	32	48	60	64	110	86	130	174	218
Combined Load Factor	28	40	46	55	104	68	86	104	122

Table D2: TSS Measured Terminal Throughput (Job Completion/min/terminal)(Equation 1)

FORTRAN	2.95	1.25	.53	.59	.315	.296	.244	.222	.195
PLISM	–	–	–	–	.077	.046	.037	.035	.034
PLILG	.48	.29	.17	.12	.057	.046	.037	.035	.034

Table D3: TSS Calculated Terminal Throughput (Job completion/min/terminal)(Equation 9)

FORTRAN	3.30	1.39	.8	.67	.30	.37	.29	.26	.23
PLISM	–	–	–	–	.063	.076	.057	.053	.048
PLILG	.53	.23	.13	.107	.046	–	.057	.039	.039

Table D4: TSS Total Measured Throughput per Script (Job Completions/min)(NT_i x TP_i^m)

FORTRAN	2.95	1.25	1.56	1.77	2.20	1.48	1.27	1.11	.97
PLISM	–	–	–	–	.23	.14	.11	.105	.102
PLILG	.48	.29	.17	.12	.228	.092	.074	.07	.068
Total*	3.43	1.54	1.73	1.89	2.66	1.71	1.45	1.29	1.14

*Total determined by $\sum_{i=1}^{6} NT_i \times TP_i^m$, Equation 5

Table D5: TSS Total Calculated Throughput per Script (Job Completion/min) ($NT_i * TP_i^c$)

Run / Script	R21	R23	R24	R25	R31	R32	R33	R34	R35
FORTRAN	3.30	1.39	2.4	2.0	2.10	1.85	1.45	1.3	1.15
PLISM	-	-	-	-	.19	.23	.17	.16	.15
PLILG	.53	.23	.13	.107	.264	-	.114	.078	.078
Total	3.83	1.62	2.53	2.11	2.55	2.08	1.73	1.54	1.38

Appendix E

MTS INTERMEDIATE RESULTS

This appendix presents the intermediate results from the MTS terminal tests that were used to prepare the figures in Section 6.5. The intermediate results were obtained in the same way that the CP results were obtained. Since Hinson made a good presentation of the intermediate results of the MTS tests in his thesis [3] these results, as shown in Table E1, were the basis for the results in this appendix.

Table E2 presents the same results as Table E1 but with several corrections to make them compatible with this project. The EDIT response times have all been reduced by 2 minutes which represents the time required to print the extra 17-1/2 lines that MTS editor produced. (See discussion in Subsection 2.2.1.) In most cases the original EDIT response times were plotted but the corrected response times were used in determining the total calculated and measured throughputs. The effective progress rates were calculated using the original EDIT response time because the corrected results would have produced unrealistically high progress rates.

The FORTEX results are corrected by multiplying the response times by 100 because the MTS tests were performed with an old version of FORTEX script that used 10,000 loops before printing 11 characters instead of the 1,000,000 used in the other tests. This is probably a little unfair to MTS since the printing time was 0.75 seconds (11 characters at 14.7 characters per second) of the 1.32 seconds minimum response time, and this does not consider the overhead of initiate the program execution, calling the clock and printing the time an extra 99 times every 2.2 minutes.

The PLILG and the PLISM response times are also corrected for Run R63 in Table E2. Run R63 was subdivided into two runs, one representing the first few minutes of R63 when the response times were good and the other representing the rest of R63 when the response times were very poor, i.e., 4 times longer than previously measured. The sub-runs are referred to as R63a and R63b.

The analysis that lead to the separation of Run R63 is shown in Figure D1. It shows an amazing consistency of the response times within the newly defined runs R63a and R63b as well as a large difference between the response times.

Table E3 shows the times that were extracted from Tables E1 and E2 for plotting the MTS terminal response graphs. Also shown are the load factors and the number of terminals assigned to each script.

Table E4 shows the MTS measured throughput per script which was determined from the last column of Table E2 by NT_i times TP_i, where NT_i is the number of terminals running script i and TP_i is the mean throughput per terminal per minute from Table E2. The total measured throughput, with the corrected throughput for EDIT, is also shown in Table E4. (Also the total throughput with the actual EDIT throughput is shown but it was not used in the analysis.

Table E5 shows the stand-alone and light load terminal response times for each script. The light load was 5 EDIT, 1 FORTRAN, 3 FORTEX and 3 PLILG for a MTS Load factor of 54. These times were used to determine the

the effective progress rates.

The effective progress rates are shown in Table E6 which were determined by dividing the minimum response times from Table E5 by the mean response times from Tables El and E2 - which are also shown in Table E6. The minimum response time for EDIT was taken from the tests rather than Table E5. The total effective progress rates, as well as the EDIT subtotals and the non-EDIT subtotals, are also shown in Table E6.

Table E1: MTS Original Response Times and Throughputs*

SCRIPT	TEST NO	RESPONSE IN MIN.				THROUGHPUT IN COMPLETIONS/ MIN/TERMINAL
		MEAN	STD DEV	HIGH VALUE	LOW VALUE	
EDIT	1	2.68	0.26	2.95	2.18	0.29
	2	2.97	0.20	3.60	2.51	0.24
	3	3.43	0.33	4.54	2.97	0.22
	4	2.96	0.25	3.59	2.50	0.27
	5	3.21	0.58	4.74	2.48	0.25
	6	3.26	0.48	4.45	2.51	0.22
	7	3.36	0.46	4.62	2.91	0.23
FORTEX	1	0.0220	0	0.022	0.022	15.15
	2	0.0239	0.0001	0.0240	0.0238	10.05
	3	0.0300	0.0002	0.0302	0.0275	8.37
	4	0.0233	0.0003	0.0236	0.0230	13.80
	5	0.0234	0.0001	0.0235	0.0233	14.35
	6	0.0250	0.0007	0.0254	0.0241	6.65
	7	- -	- -	- -	- -	- -
PAGE	1	- -	- -	- -	- -	- -
	2	- -	- -	- -	- -	- -
	3	- -	- -	- -	- -	- -
	4	- -	- -	- -	- -	- -
	5	0.97	0.40	1.49	0.22	0.31
	6	- -	- -	- -	- -	- -
	7	- -	- -	- -	- -	- -
PLILG	1	2.86	0	2.86	2.86	0.31
	2	3.97	0.41	4.47	3.26	0.17
	3	21.00	14.54	37.22	6.71	0.025
	4	2.94	0.40	3.54	2.32	0.32
	5	6.13	1.08	8.01	4.83	0.18
	6	6.85	1.48	9.43	5.73	0.063
	7	6.70	1.12	9.08	4.77	0.13
PLISM	1	- -	- -	- -	- -	- -
	2	2.36	0.23	2.63	2.16	0.29
	3	7.24	4.40	11.67	2.94	0.11
	4	1.71	0.20	1.85	1.57	0.22
	5	3.55	0.94	4.75	2.52	0.17
	6	3.61	0.52	4.39	2.99	0.19
	7	3.53	1.26	4.45	2.10	0.24
FORTRAN	1	0.37	0.21	0.59	0.18	0.57
	2	0.41	0.21	0.82	0.20	1.49
	3	1.16	1.03	3.81	0.25	0.31
	4	0.36	0.26	0.89	0.20	1.67
	5	0.60	0.28	1.19	0.22	1.86
	6	0.67	0.39	2.70	0.20	1.06
	7	0.58	0.34	1.74	0.20	1.14

*Obtained from Hinson's thesis [3].

Table E2: MTS Corrected Response and Throughput

		RESPONSE IN MIN.				MEASURED THROUGHPUT IN COMPLETIONS/ MIN/TERMINAL
SCRIPT	TEST NO	MEAN	STD DEV	HIGH VALUE	LOW VALUE	
EDIT	R61	0.68*	-	0.95	0.18	1.14*
	R62	0.97	-	1.60	0.51	.73
	R63	1.43	-	2.54	0.97	.53
	R64	0.96	-	1.59	0.50	.83
	R65	1.21	-	2.74	0.48	.66
	R66	1.26	-	2.45	0.51	.57
	R67	1.36	-	2.62	0.91	.57
FORTEX	R61	2.20		2.2	2.2	.151
	R62	2.39	0.01	2.40	2.38	.100
	R63	3.00	0.02	3.02	2.75	.083
x 100	R64	2.33	0.03	2.36	2.30	.138
	R65	2.34	0.01	2.35	2.33	.143
	R66	2.50	0.07	2.54	2.41	.066
	R67	-	-	-	-	-
PAGE	R61	-	-	-	-	-
	R62	-	-	-	-	-
	R63	-	-	-	-	-
	R64	-	-	-	-	-
	R65	0.97	0.40	1.49	0.22	0.31
	R66	-	-	-	-	-
	R67	-	-	-	-	-
PLILG	R61	2.86	0	2.86	2.86	0.31
	R62	3.97	0.41	4.47	3.26	0.17
	R63a	8.5	4.4	12.0	6.71	} 0.025
	R63b	35.4	7.94	37.22	28.3	
	R64	2.94	0.40	3.54	2.32	0.32
	R65	6.13	1.08	8.01	4.83	0.18
	R66	6.85	1.48	9.43	5.73	0.063
	R67	6.70	1.12	9.08	4.77	0.13
PLISM	R61	-	-	-	-	-
	R62	2.36	0.23	2.63	2.16	0.29
	R63a	3.2	.39	3.5	2.94	} 0.11
	R63b	11.0	1.31	11.67	10.0	
	R64	1.71	0.20	1.85	1.57	0.22
	R65	3.55	0.94	4.75	2.52	0.17
	R66	3.61	0.52	4.39	2.99	0.19
	R67	3.53	1.26	4.45	2.10	0.24
FORTRAN	R61	0.37	0.21	0.59	0.18	0.57
	R62	0.41	0.21	0.82	0.20	1.49
	R63	1.16	1.03	3.81	0.25	0.31
	R64	0.36	0.26	0.89	0.20	1.67
	R65	0.60	0.28	1.19	0.22	1.86
	R66	0.67	0.39	2.70	0.20	1.06
	R67	0.58	0.34	1.74	0.20	1.14

* 2 minutes subtracted from results in Table E1,
i.e., .29 x 2.68/0.68 = 1.14

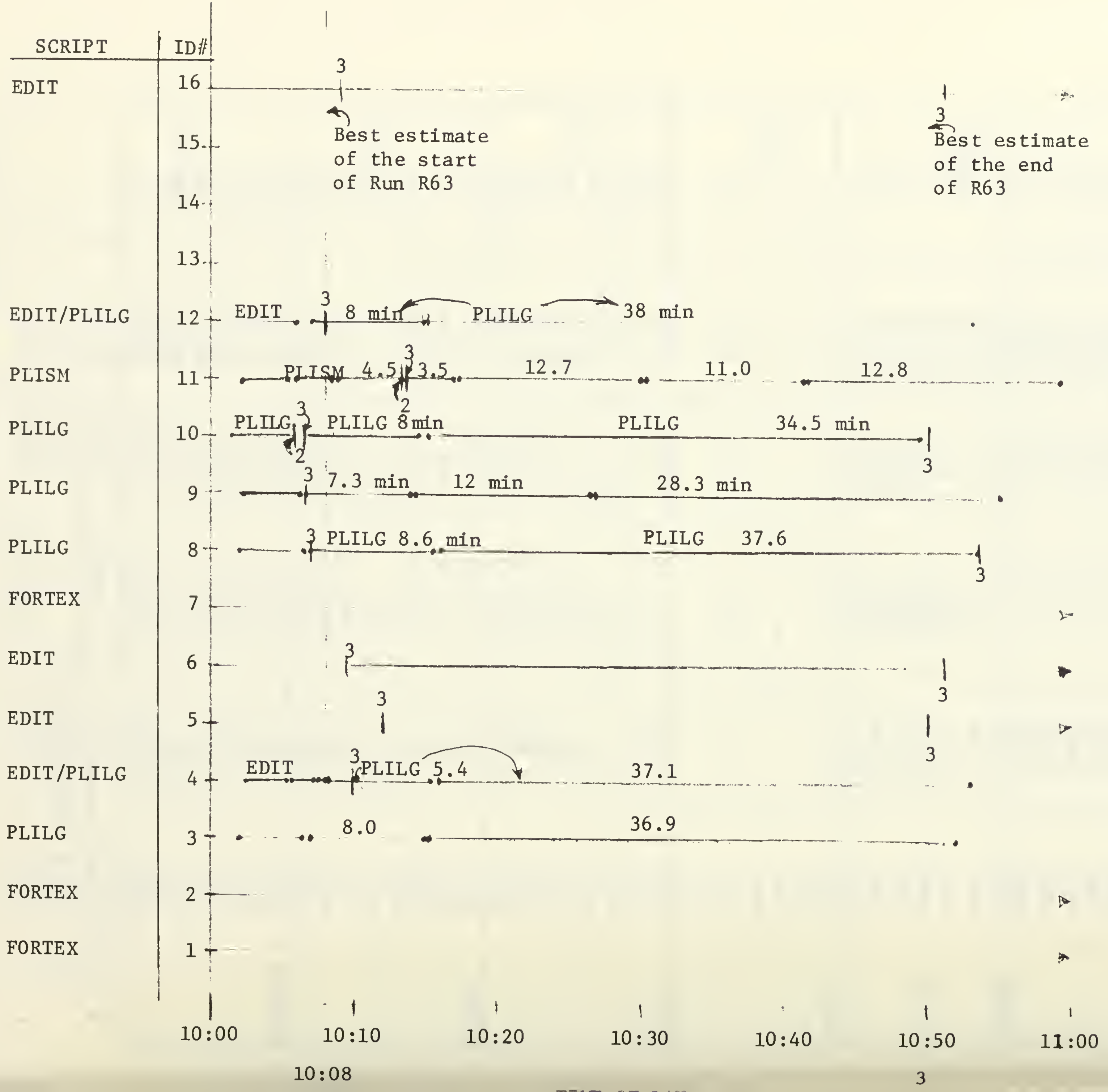
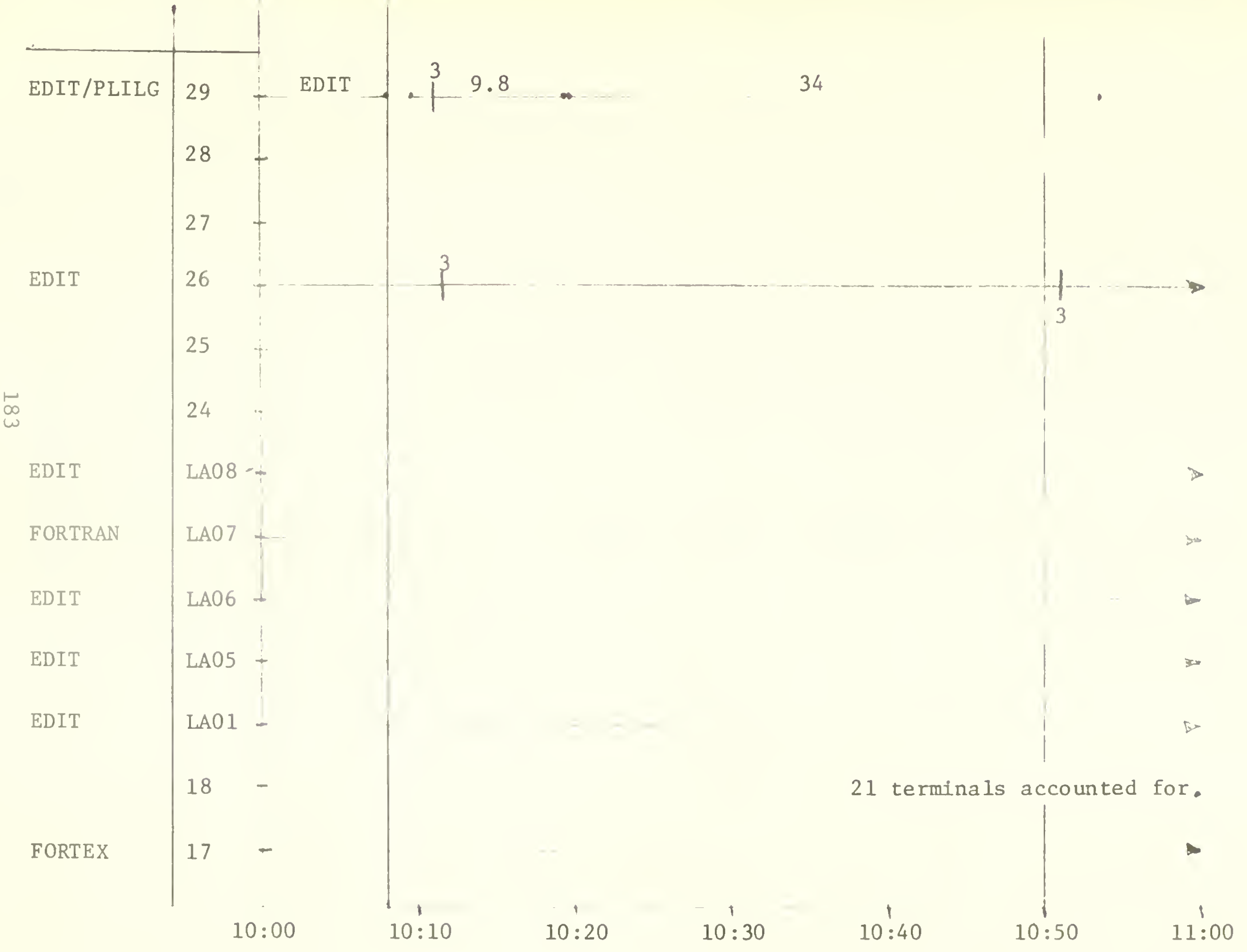


Figure E1: Time Analysis of MTS Run R63

Figure E1 (cont'd): <u>Time Analysis of MTS Run R63</u>



21 terminals accounted for.

Table E3: MTS Mean Terminal Response Times Used in Graphs (in Minutes)

RUN	LOAD FACTOR			EDIT	FORTEX	PLISM	PLILG	FORTRAN	#	#	#	#	#	#
#	CP	MTS	COMB	R.T.	R.T.	R.T.	R.T.	R.T.	EDIT	FORTEX	PAGE	PLILG	PLISM	FORTRAN
R61	48	44	39	2.68	2.20	-	2.86	.37	11	3	0	1	0	1
R62	86	84	77	2.39	2.39	2.36	3.97	.41	13	4	0	4	1	1
R63a	104	142	98	3.43	3.00	3.2	8.5	1.16	10	4	0	7	1	1
R63b	104	142	98	3.43	3.00	11.	35.4	1.16	10	4	0	7	1	1
R64	86	84	72	2.96	2.33	1.71	2.94	.36	8	4	0	4	1	1
R65	114	98	102	3.21	2.34	3.55	6.13	.60	8	3	2	4	3	3
R66	110	132	101	3.26	2.50	3.61	6.85	.67	5	6	0	4	3	5
R67	98	113	80	3.36	-	3.53	6.70	.58	12	0	0	7	1	3

Table E4: MTS Measured Throughput per Script*

Run Script	R61	R62	R63	R64	R65	R66	R67
EDIT (actual; Table E1)	3.19	3.12	2.20	2.16	2.00	1.10	2.76
FORTRAN	.57	1.49	.31	1.67	5.58	5.30	3.42
FORTRAN (Corrected)	.45	.40	.34	.55	.43	.40	-
PLISM	-	.29	.11	.22	.51	.57	.24
PLILG	.31	.68	.18	1.28	.72	.25	.91
TOTAL	4.42	5.98	3.14	5.88	9.24	7.62	7.33
EDIT (corrected: Table E2)	12.5	9.5	5.3	6.6	5.3	2.9	6.8
Subtotal without EDIT	1.33	2.86	.94	3.92	7.24	6.52	4.57
Total with corrected EDIT	13.8	12.4	6.2	10.5	12.5	9.4	11.4
Combined Load Factor	39	77	98	72	102	101	80
MTS Load Factor	44	84	142	84	97	132	113

Table E5: MTS Minimum Terminal Response Time

SCRIPT	SINGLE JOB IN SYSTEM	12 JOBS IN SYSTEM
EDIT	2.84**	2.85
FORTEX	-	0.28
FORTRAN	0.18	0.18
PAGE	0.18	-
PLILG	1.64	1.93
PLISM	1.06	-

*Determined from last column of Table E2 by NT_i x $\overline{TP}_i$ where NT_i is the number of terminal running script i and $\overline{TP}_i$ is the mean throughput per terminal per minute.

**Too high; the lowest value in the tests was 2.18 minutes.

Table E6: MTS Effective Progress Rates

Run Mean Response Times - Tables E1 and E2	R61	R62	R63a	R63b	R64	R65	R66	R67	Stand-alone
EDIT	2.68	2.97	3.43		2.96	3.21	3.26	3.36	2.18
FORTRAN	0.37	0.41	1.16		0.36	0.60	0.67	0.58	0.18
FORTEX	2.20	2.39	3.00		2.33	2.34	2.50	-	0.28
PLISM	-	2.36	3.2	11.0	1.71	3.55	3.61	3.53	1.06
PLILG	2.86	3.97	8.5	35.4	2.94	6.13	6.85	6.70	1.64
Mean Effective Progress Rates									
EDIT	0.813	0.735	0.635		0.737	0.68	0.67	0.65	1
FORTRAN	0.49	0.44	0.155		0.50	0.30	0.27	0.31	1
FORTEX	0.127	0.117	0.093		0.12	0.12	0.112	-	1
PLISM	-	0.45	0.33	0.096	0.62	0.30	0.294	0.30	1
PLILG	0.574	0.413	0.19	0.045	0.56	0.268	0.24	0.245	1
Total*	10.39	12.56	8.56	7.29	9.74	8.77	7.23	10.75	
Subtotal for EDITs	8.95	9.55	6.35	6.35	5.90	5.44	3.35	7.80	
Subtotal for Non-EDITs	1.44	3.01	2.21	0.94	3.84	3.33	3.88	2.95	

*Total Effective progress rates = $\sum_{i=1}^{5} NT_i * EPR_i$, where NT_i and EPR_i are the number of terminals running script i and its mean effective progress rate, respectively.

Appendix F

BATCH INTERMEDIATE RESULTS

The intermediate data from a late version of the MTS batch benchmarking runs is shown in Figure F1. The data includes the starting, stopping, elapsed and CPU times and the lines of printed output for each job. Also shown are the order of job initiation and the total elapsed time. These tests on jobstream A and B were performed in September 1971.

The intermediate data for OS benchmarking tests performed in November of 1969 under OS/MVT version 15/16 are shown in Table F2. The data includes the total turnaround times, the times in which at least 3 jobs were in the system and the multiprogramming times.

A summary of above MTS and OS results as well as some other tests on MTS and TSS is shown in Table F3 which summarizes the total turnaround time for each jobstream and configuration.

Table F1: MTS Batch Benchmarking Results - Sept/71

Part 1 Jobstream A

Times Jobs	Start time (ON) (hours:min:sec)	Stop Time (OFF) (hours:min:sec)	Elapsed Time (seconds)	CPU Time (seconds)	Lines Printed
SYS001	5:42:07	5:42:27	20.8	15.0	189
SYS003	5:42:34	5:42:48	14.0	5.16*	476
SYS002	5:42:31	5:43:10	38.7	19.1	1243
SYS005	5:43:17	5:43:53	35.9	10.9	300
SYS011	5:45:12	5:46:08	55.9	10.6	278
SYS004	5:43:05	5:44:18	72.4	21.7	602
SYS008	5:44:12	5:45:16	64.1	14.4	409
SYS010	5:44:49	5:45:52	63.0	9.39	658
SYS007	5:43:57	5:45:09	71.3	19.3	1213
SYS006	5:43:32	5:45:18	106.0	17.7	1227
SYS015	5:46:12	5:51:23	311.0	93.0	74
SYS014	5:46:00	5:51:37	366.4	93.4	74
SYS012	5:45:21	5:46:33	71.5	18.4	1232
SYS009	5:44:41	5:46:45	123.8	21.3	1178
SYS013	5:45:38	5:56:05	626.7	364.1	604

Order of job starts: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15
Total Turnaround Time = 5:56:05 - 5:42:07 = 13:58 = 13.97 Minutes

Part 2: Jobstream B

Times Jobs	Start Time (ON) (hours:min:sec)	Start Time (OFF) (hours:min:sec)	Elasped Time (seconds)	CPU Time (seconds)	Lines Printed
SYS001	-	-	≃21.	-	-
SYS002	13:03:33	13:06:26	173.0	19.4	1029
SYS004	13:04:06	13:07:08	182.2	21.0	69
SYS008	13:06:13	13:07:25	71.7	12.2	183
SYS007	13:06:06	13:06:43	42.5	18.8	1029
SYS011	13:06:58	13:08:11	72.5	10.2	57
SYS006	13:04:33	13:06:47	135.0	15.6	973
SYS009	13:06:35	13:07:44	68.8	20.5	716
SYS015	13:07:51	13:10:43	171.6	91.5	59
SYS014	13:07:29	13:10:46	196.9	91.6	59
SYS010	13:06:48	13:07:44	55.6	8.95	550
SYS012	13:07:12	13:08:13	60.6	15.3	973
SYS013	13:08:01	13:15:24	443.2	363.3	251
SYS003	13:03:35	13:05:52	136.7	5.11**	459
SYS005	13:04:18	13.06:10	112.0	10.6	118

Order by Start time: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 15, 13
Total Turnaround Time = 15:24 - 03:33 = 11:51 plus 21 sec = 12.2 minutes

*CPU time limit exceeded on SYS003

**Normal termination

Table F2: OS/MVT Batch Benchmarking Results

Configuration	Job-stream	Total Turnaround Time (minutes	Third-in to Third-out Time* (minutes)	Multi-programming Time** (minutes)
3 core boxes	A	22	10	18
	B	22	12	17
	C	26	15	16
2 core boxes	A	24	13	20
	B	22^+	11	17
	C	27^+	16	7

Table F3: Summary Batch Total Turnaround Times (minutes)

System	Configurations	Jobstream		
		A	B	C
OS/MVT	3 core boxes	22	22	26
	2 core boxes	24	22^+	27^+
TSS	3 core boxes Dual processor	20	16	14
	3 core boxes Single processor	26	21	21^+
	2 core boxes Single processor One channel Control Unit	41^+	31^+	27^+
MTS	3 core boxes Dual processor	12.5	11.3	10.0
Summer 1970	2 core boxes Single processor One channel Control Unit			19.5
MTS Sept/71	3 core boxes Dual processor	13.97	12.2	

*Third-in until third-out time means the time in which at least 3 jobs were in the system.

**Multiprogramming time means the time in which at least 2 jobs were executing.

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13. ABSTRACT

A set of terminal scripts and benchmarks have been derived for comparing the performance of time sharing and batch computer operating systems. Some of the problems encountered in designing valid benchmarks for comparing computer operating systems under both terminal and batch loads are discussed.

The results of comparing TSS/360, CP/67 and MTS time sharing systems for the IBM 360/67 over a wide range of load conditions are presented. The results of comparing TSS, MTS and OS/MVT under batch loads are also presented.

Serious performance degradation of the time sharing computer systems from overloading was experienced and a simple solution is suggested to prevent such degradation. The degradation was so sever as to render the performance less than that of a sequential job processor system.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Benchmarking						
Performance						
Evaluation						
Time Sharing System						
Time Sharing						
Computer Performance Evaluation						
Measurement						
Terminal Scripts						
Operating System						
Computer						
CP/67						
CP/CMS						
TSS/360						
MTS						
OS/MVT						
IBM 360/67						
Michigan Terminal System						
Load Factor						
Effective Progress Rate						
Computer Perforamnce						
Batch System						