Minutes
NCAR Computing Facility Advisory Panel
Meeting of 9 August 1971

Panel Members

Attendees: Ronald Lavoie, Acting Chairman
Julian Bigelow
Cecil Leith

Absent: Jim Douglas
Bernard Galler
Mario Juncosa, Chairman
George Platzman

NCAR Staff

Jeanne Adams
Robert Biro
Ted Hildebrandt
Roy Jenne
Charles Palmer
David Robertson
Paul Rotar

It was noted that four of the seven panel members were absent, but since there are no formal procedures regarding a quorum or acting chairman for panel meetings, Charles Palmer suggested that Ronald Lavoie serve as acting chairman and that the meeting proceed.

A. Minutes of Last Meeting, 22 March 1971

Ted Hildebrandt relayed a question George Platzman had on the minutes (Platzman had contacted Hildebrandt by telephone): Did the panel not go on record as opposed to NCAR's joining the ARPA computer network? Julian Bigelow said he thought the panel advised caution in joining the net, but was not opposed to it. The Computing Facility should guard against the net's becoming a research project in itself and occupying two-thirds of the time of some of our best people, he said.

Ronald Lavoie asked to know the reference of the publication on mathematics as it relates to meteorology, which Jim Douglas mentioned at the last meeting (page 5 of the minutes). [Douglas was contacted, but did not recall making reference to such a publication.]

Lavoie said that Árnason, whose request for computer time was considered at the last meeting, will be leaving the Center for Environment and Man, Inc. and will be going to the State University of New York at Albany in the fall of 1971.
Regarding the non-NCAR user project completion report, Bigelow suggested that a better idea of the significance of the respondent's answers could be gained by adding the question "How much experience have you had in the field of meteorology on computing projects?" Bigelow suggested that we may find that certain people do most of the good computing and perhaps a conference could be held with those people in attendance to determine what is important and what is not.

Palmer suggested requests for project completion reports go out over John Firor's signature, as they do for the Aviation and Balloon Facilities. Essentially two questions are asked on their forms: "What are your preliminary results?" and "Were the operational aspects satisfactory?" Lavoie questioned the necessity for the second question, and Palmer answered that even though the facility's performance is good, sometimes the user's results are not good. Bigelow questioned the wisdom of asking users to evaluate their results. Regarding the Computing Facility users, Cecil Leith said that if we don't receive copies of their publications, we may conclude there were no results.

Leith said some users thought the questions were too detailed and not all relevant to their projects. It was suggested that the questions be prefaced with "The purpose of this form is to see how well our facility meets your needs," and "Please answer the appropriate questions."

Hildebrandt will review the project completion report, which is being used on an experimental basis.

Regarding the computer resource units (CRU), Lavoie asked how the CP/PP overlap is handled. Hildebrandt said CP and PP are measured and recorded separately regardless of the overlap. We are more concerned about problems whose PP exceeds the CP time.

Lavoie asked how the CRU weighting factors were determined. Hildebrandt said they are based more or less on costs of the items considered in the formula, but they are by no means true representations. Leith said the purpose of CRU is to encourage users to optimize the equipment, which does not necessarily relate to hardware costs.
Several suggestions were made for consideration in the CRU scheme. Bigelow suggested charging the user for rearrangement in core when that user's job made necessary the rearrangement. A good charging system might take into consideration factors like "machine tie-up" or "useless traffic." Hildebrandt said we might consider adding some constant times the total CPU time, the constant representing the red tape of getting the problem in the machine. Leith suggested the CRU scheme take into account the relative cost of arithmetic.

Leith said that with the present CRU scheme, there will be a tendency to use I/O and in the past the high number of I/O bound jobs had been a problem. Hildebrandt said this problem has gotten worse. With the CDC 7600 running five times as fast as the 6600, there are five times as many tape mount requests. Also, the peripherals on the 7600 run at the same speed as those on the 6600. A revised CRU scheme will be considered in six months or a year.

Bigelow asked if a user knows what his compile time is. Leith answered that it is printed on the listing, but NCAR's compiler is so efficient that there is no need to worry about it. Bigelow asked if we advise users when it would be best to recompile and when to use binary. Leith said that users are generally advised to recompile each time. Bigelow suggested it might be worthwhile to consider using lots of subroutines to help cut down the compile time. Hildebrandt said subroutine calls sometimes waste a lot of time, particularly if there is a lot of segmentation. Leith suggested incorporating into the accounting system the total compile time of jobs.

The minutes were approved as written.

B. Non-NCAR Requests Requiring Panel Action

Hildebrandt said Platzman's general reaction (by phone) to all the requests was favorable, but Platzman noted that some users are projecting their needs a long way ahead and wondered if some limitation should be made on the maximum amount of time the panel would approve at any one time.
Minutes

Lavoie felt the panel had been doing this informally and suggested that no formal rule be made. Hildebrandt agreed, adding that when we have been unsure of the basis on which a request is made or unsure of the abilities of the requestor, we have limited the grant and ask for a review of the progress made before granting additional computer time.

In determining the amount of the resource requested by non-NCAR users, Hildebrandt said a ratio of five 6600 CPU hours to one 7600 CPU hour is used, and that grants are made only in terms of CRUs. Dollars are not specified. A request which does not specify 6600 or 7600 time is considered in terms of 6600. Or CRUs may be specified.

Lavoie noted that Houghton's request for computer time was made prior to submission of his proposal to NSF and that use of NCAR's computers is central to his NSF proposal. He asked if there were a policy governing simultaneous requests to funding agencies and to NCAR for computer time. Should NCAR's decision await the funding agency's decision?

Other considerations were mentioned. If a proposal asks for funds for computer time at the home institution and NSF suggests NCAR be contacted for free computer time, there is a danger of undermining the university computer centers. NSF may recommend whether the home facility or the NCAR facility is to be used, but the final determination of the use of the NCAR facility has rested with the Computing Facility Advisory Panel regardless of the NSF decision on the grant.

Bigelow felt grants of NCAR computer time should be made after the funding agency has approved the proposal. He said there are two questions about a proposal: Is it good science and is it good computing? NSF could judge the first, and NCAR the second. Bigelow suggested that a letter from NCAR to NSF could contain a technical evaluation of the computing aspects of a proposal, but could make clear that NCAR does not wish to get involved in deciding about finances or in deciding which computing facility should be used.

Lavoie said that NSF probably refers prospective grantees to NCAR's computers because NSF funds NCAR and fears that a certain fraction of computer time may go unused unless university scientists are encouraged to use it.
Hildebrandt said NSF should be advised of the nominal value of the computer request. For example, Houghton's proposal to NSF states that there is no charge for computer time, which is true, but the resource is being paid for. Sometimes an NSF proposal in fact requests less funds than the value of the computer time requested at NCAR.

The consensus of the panel was that NCAR grants should be conditional to NSF approval of the research proposal. If NSF does not approve the proposal, NCAR could then decide after consultation with the NSF contract officer whether to grant computer time.

Houghton - 225,000 CRU

Hildebrandt read a letter from Houghton dated 6 August 1971 stating that his proposal had been approved, but the budget had been reduced. The letter asked the panel to consider authorization for the Computing Facility programmers assigned to the general circulation model (GCM) to assist Houghton on his project. Hildebrandt said that if we were to do this, the GCM effort at NCAR would have to be reduced, and that at present it appears that we will be unable to add staff in either FY 1972 or FY 1973.

Leith said the GCM scientists are not eager to offer programming support for Houghton's request. Lavoie asked if the GCM group plans to study aerosols, and Leith said they have such plans for the future. However, Houghton asked Kasahara to sponsor his request and was turned down. The concern is the demand which will be made on the GCM programmers. The GCM scientists are not yet ready to open up the GCM to other users. When they do open it up, of course, the GCM programmers will have to be available for consultation on its use.

The panel recommended Houghton be granted 120,000 CRU with the stipulation that programming assistance beyond the normal consultation given to non-NCAR users will not be available, and with the suggestion that he seek programming support on his own. Frank Eden, the NSF contract officer, will be sent a copy of the letter.
Huang - 30,000 CRU

The panel was pleased to see a study in air-sea interaction, and Huang's request was approved in full.

Orville - 60,000 CRU and 30,000 CRU

Leith noted that Orville's first request was a continuation of previous work and that the second one on hurricanes was new and looked quite interesting. The panel enthusiastically approved his requests in full.

Ranga Rao - 18,000 CRU

The panel was skeptical that Ranga Rao's project could be completed by March 1972, but noted he has a viable approach to the numerics. His request was approved in full, but the completion date was extended to 31 August 1972.

Try - 12,000 CRU

The panel felt that Try had looked into the radiation transfer problem sufficiently to be quite converive on the techniques involved and approved his request in full.

Warn-Varnas - 60,000 CRU

The panel noted that Warn-Varnas will choose between two different numerical approaches. The panel questioned whether he would need as much time as he requested, and granted 30,000 CRU with the suggestion that he advise the panel of his results with that time at either the November or spring meeting when an extension request will be considered if necessary.

Wilhelmson - 27,000 CRU

Hildebrandt said that Ogura's associates had made efficient use of the computer in the past. The panel felt the request was scientifically competent and approved the request in full.

Lavoie noted that this request was specifically geared to the 7600. Hildebrandt said that it will not be necessary for him to use only the 7600 and that we have advised him how to program the problem so that it can be run on either machine. We try to avoid having problems tied to only one machine,
except that I/O bound jobs should be run on the 6600 since they will be even more I/O bound on the 7600. The CRU limits will determine on which machine jobs will be run.

C. Non-NCAR Requests Approved by TWH Since Last Meeting

Hildebrandt reviewed the background to the Christopher Brown request. Originally, his request had indicated only that he wished to use the computer for binary coding and his request was turned down. It then developed that he was working on a device for x-ray pictures of the sun.

Lavoie questioned whether Edgar Everhart's work on perturbed orbits of comets should have been approved. He felt that studies of the atmosphere of a comet fall under the field of astronomy rather than atmospheric science. It was suggested that HAO could be contacted in the future to determine whether similar studies were areas in which HAO has an interest.

Hildebrandt called to the attention of the panel a letter from Gale Biggs dated 22 July 1971 advising us that he is joining a consulting firm, but would like to finish up his Iowa State work at NCAR. Hildebrandt had suggested that he complete it as soon as possible, and the panel suggested if the project is not finished by the expected completion date, a request for extension should be reviewed by the panel.

D. 7600 Approval Authority for TWH

Hildebrandt said that at present he is authorized to approve only two 7600 CPU hours. Since we don't wish to guarantee on which machine jobs will be run, he suggested the Head of the Computing Facility be authorized to grant either 15,000 or 30,000 CRU, the equivalent of five or ten 7600 hours, respectively. Palmer added that since we now have a bigger capacity, a greater percentage approval should be authorized. He said the approval limit on the 3600 (before the 6600) was ten hours also.

Since this would be a policy change, Bigelow felt that it should be considered by the whole panel. The panel will be solicited by mail for a decision on an approval limit of 30,000 CRU (ten 7600 hours) by the Head of the Computing Facility for non-NCAR requests for computer time.
Bigelow feared that such action would create a tendency for people to ask for 7600 time. Hildebrandt said this was not the case, since he would be able to approve up to fifty 6600 hours.

Lavoie said that if the goal is 25% non-NCAR usage, then the present 6,000 CRU limit would put a much larger burden on the panel. He felt a larger fraction of these requests should be handled locally. Leith suggested that we want to encourage the use of both machines to capacity.

E. Five-Year Plan

Hildebrandt reviewed the five-year plan for the Computing Facility, a draft version of which was presented to NSF in late July 1971. It reviews the current status of the array type processors (Control Data's STAR, Burroughs' ILLIAC IV, and Texas Instruments' Advanced Scientific Computer (ASC)), with respect to availability, machine cost, and installation cost. We expect to have need for an array processing machine by FY 1975 in order to carry out the research which appears likely in the next five years, and, at present, the STAR appears to be the best choice. Another recommendation is that the 7600 be purchased within about one year. At the time the array processor is installed, the 6600 would be released. The reason for purchasing the 7600 and releasing the 6600 is that because the 6600 is an early serial number, we cannot add extended core storage or additional PPs without a major (about $1 million) overhaul. The 7600 is also much easier to adapt to handle teleprocessing than the 6600 is. Viewgraphs (attached) of some of the draft version of the five-year plan were shown.

Attachment A shows estimates of the computing requirements of the GCM in terms of 6600 years, assuming there will be an array processor. These estimates show the GCM using 70% of the 7600 by FY 1973.

Attachment B shows the projection of NCAR computer usage for the period FY 1971-76, assuming two drums will be added to the 7600 in FY 1973 and an on-line mass storage device added in FY 1974. With an array processor in FY 1975, the computing power available at NCAR would increase to the equivalent
of about 250 6600 computers. Attachment B shows what portions of the computing resource would be used by the GCM, turbulence and convection (T&C), university users, and others. Under the category of "others" are included non-modelling problems, problems not suitable for an array processor. We believe the non-modelling activities will increase beyond the capacity of the 6600, but could be handled by the 7600. T&C is expected to increase to about one-half the usage of the GCM by FY 1975, and university users are expected to use up to 25% of the computing resource.

Attachment C indicates the cost effectiveness of the computers under consideration. Hildebrandt explained how these figures were computed. While they are admittedly artificial, they do give us something to go on.

Lavoie made reference to a report by Smagorinsky* ["Problems and promises of deterministic extended range forecasting," *Bul. Am. Met. Soc.*, Vol. 50, No. 5, May 1969, pp. 286-311] which indicates that the STAR is only a factor of two greater in speed than the 7600 and an order of magnitude slower than the ILLIAC IV. Hildebrandt had not yet read the report, but indicated that there are several problems not yet resolved with the ILLIAC. One problem is the relatively small amount of core storage. Fixed head disks are used as back-up store, and apparently once high-speed store is used up, the machine must stop and wait, a wait which is long in terms of the machine's maximum computing speed. Burroughs has not yet indicated a solution to this problem, whereas Control Data is providing a large buffer store and disks or drums to back up the buffer store in an effort to get better throughput. Texas Instruments is also working on this problem.

Because of the cooling problem, a new building would have to be built to house the ILLIAC IV. Both the ASC and STAR could be installed in our present location with relatively minor site preparations.

*Note by T. W. Hildebrandt: The reference contains Fig. 12 which is evidently based on information available in 1968, since the referenced lecture was delivered at the 49th Annual AMS meeting, 20 January 1969. At that time the first CDC 7600 was being installed at Livermore, and the STAR and ILLIAC were both "paper" machines. There is no indication in the referenced paper of the source of the data presented in Fig. 12.
Hildebrandt said Control Data has not yet decided if the STAR will be a special order device or sold as a regular product. Leith said that if Control Data decides to build the 8000 series, they may be reluctant to assemble STARS. Hildebrandt said Texas Instruments will take orders now with delivery 18 months to 2 years from date of order. Burroughs has not yet decided whether to market the ILLIAC. IBM has said nothing yet about a machine competitive with these. Texas Instruments' software is far superior to that currently available for the other two machines.

Leith said that at present the competition appears to be between a four-pipeline ASC and the STAR; however, the ASC costs $4 \times 10^6 more than the STAR, and the STAR is also more easily installed than the ASC or ILLIAC. Hildebrandt said benchmarks will, of course, have to be run on existing machines or prototypes before a decision can be made.

Attachment D delineates the budget projections for the proposed five-year plan. Funds must be requested a year before purchase of the 7600 and before installation of an array processor.

Attachment E shows the 7600 cumulative expenditures, taking into account lease price plus purchase price at each fiscal year. The cross-over point occurs in FY 1976. Leith pointed out that purchasing the 7600 is largely up to UCAR and NSF. Control Data lease and purchase prices are structured such that differences between them are small.

Palmer said a recommendation to purchase the 7600 would probably be made to UCAR in November, December or January. It would be well to get the panel's recommendation on this question at the November 1971 meeting.

When the five-year plan is in better shape, it will be reviewed by the panel.

F. Special Handling of Extended Programs

The panel reviewed the procedures set up for special handling of data processing for extended experimental-observational programs. Hildebrandt said the NCAR Directors felt this procedure was needed for repetitious programs where answers were needed by a certain time, but that one-time operations will continue to be handled individually and verbally.
G. Review of Operations

Systems

Paul Rotar reported on the systems effort for the 7600. He relayed some of the problems encountered in Minneapolis when trying to debug the software. The machine was running reasonably well about 22 June, and by 12 July the software was solid. There have been only two software problems since then. Debugging the software on the 6600 and simulating it on the 7600 saved a lot of time.

Rotar mentioned some hardware discrepancies between the 6600 and 7600, and how they were being overcome. There were changes in the rounding, floating multiply and the 02 jump instruction. But for the most part, the CPU hardware is nearly the same in both machines. Another change was that K (in 512K large core memory) meant 1000 instead of 1024 in this case. The remaining 12K core cells are in the large core memory, but are not available for use. The 512 printer speed is highly variable because there are fewer of some of the special characters.

Remote Terminals

Rotar said we are just now starting to initiate plans for remote terminals. Once the 7600 is set up for one terminal, others could be added also.

Leith asked if the terminals would use standard telephone lines. Hildebrandt said yes, except that NCAR's terminal at 30th Street or HAO would use a direct line. The teleprocessing will probably operate on a batch processing basis. If a user's results are not returned within a few minutes, it may be more economical to cut off the user and send his results later.

Lavoie asked what kind of equipment the remote user will need. Hildebrandt said the rate of communication should be about 2,000 bits per second. Control Data's U-200 terminal with a reader, printer and console rents for about $1,000 per month. Other terminal systems can be used, however. Control Data's reader and printer could be operated at full speed provided all 80 card columns were not used.
Hildebrandt said programmer consultation will not be available to remote users to the extent it is now to the non-NCAR users. We may have to provide some means of direct communication, perhaps by telephone, between the remote user and an NCAR programmer.

Lavoie suggested some thought be given to establishing an NCAR-operated remote terminal facility, say on the East Coast, where several institutions could use it jointly. Hildebrandt asked Lavoie how he felt users would react if we offered remote access to NCAR computers on an FOB Boulder basis. Lavoie said he felt most users would not have enough work to warrant a facility such as this, but that a facility within, say, 200 miles from several users might be warranted. He said that some university people further away from NCAR feel nearby people have an advantage over them.

Lavoie asked why NSF thinks it would be desirable for NCAR to join the ARPA computer network. Hildebrandt said it is a means of providing remote access to NCAR computers without great expense to NSF or other users. We originally wanted to restrict use of NCAR's computers on the net to problems in atmospheric science, but it appears we will not be able to. We may be able to give priority to atmospheric problems. Leith said one of the advantages of the net to NCAR is the availability of a very large store.

Lavoie asked if the ARPA net is to communicate directly with core or on a batch processing basis. Hildebrandt said that the ARPA net is designed essentially for interactive processing, but it can be used in a batch processing mode. Each node will be connected to the net by an Interface Message Processor which will take care of moving messages. One card will equal one message, and each message may not get to the host computer via the same route.

Roy Jenne said he attended an ARPA meeting to discuss the ARPA database. They are hoping to use a laser store to hold a file of ten years of surface and upper air data for the period 1966-1976. They will probably be able to make the data available on the net. Some of the high volume derived data cannot be kept on-line because only $10^{11}$ bits of storage can be used for meteorology; the total ten-year set contains about $5 \times 10^{11}$ bits.
Lavoie asked if it were worthwhile to have rapid access to climatological data. Jenne said that the National Hail Research Experiment will want access to current data. Most users of climatological data can wait at least some days or weeks for the data they need. Leith asked if the National Meteorological Center intends to join the ARPA net, and Jenne said it does not, as far as he knows.

Operations

Robert Biro reported that the requirements for operations staff for the 7600 were underestimated, and we are currently hiring additional computer operators. The high number of tape mount requests has slowed turnaround. He said the 7600 hardware was installed smoothly, and as of 8 August, the acceptance test shows 93.11% uptime.

Hildebrandt explained that the acceptance test is that the machine must show 90% uptime for 30 consecutive days. The acceptance test began on 31 July 1971. If the acceptance test is not successful after 90 days have elapsed, NCAR has the option to reject the machine.

Biro said the 7600 is deadstarted frequently. The machine goes down about every hour during the day shift; on weekends it runs for several hours at a time. Most of the errors are parity errors in large and small core. Hildebrandt said we may also be getting heating problems because our software hits the hardware harder than the vendor software does.

Since there is no software function to recheck parity errors, Bigelow suggested that a fair number of duplicate programs be run to see if the results check exactly.

Regarding the operation load, Leith said with the faster arithmetic now available, it takes relatively longer to read the cards and mount the tapes. He projected that users will learn to think in terms of five-minute jobs instead of one-minute jobs. Hildebrandt said that this problem will be alleviated when the acceptance test is completed and short jobs are run on the 6600 and long jobs on the 7600.
Training

Jeanne Adams reported that this year the Summer Fellowship Program in scientific computing included how to use the 7600 effectively, program design, and development of large models. There was less interest in assembly language this year. A series of modelling seminars was given by scientists and their lead programmers. These seminars were open to the NCAR public as well. Requests for training programs seem to remain the same even though we are not increasing the staff at NCAR.

Data

Roy Jenne said his group has continued to gather data on the tropics, and has sent some of this data to universities. Jenne has also been involved in data planning for some of the CARP experiments. This month he will attend a planning meeting in Moscow for the Tropical Atlantic Experiment to be held in 1974. On his return, he will visit several European installations to inquire about oceanographic data which will be needed soon by groups at NCAR.

Hardware

May 1971

Hildebrandt reported that the 7600 hardware was very smoothly moved into the building the last week in May. The power was on within two or three days, and the hardware was showing solid signs of life about 22 June. The main problem with the hardware was that about one-third of the total 3600 modules had to be replaced. One problem with the hardware is our own doing. We had originally intended to get a 254 microfilm recorder for $150,000, but later decided a second dd80 would better suit our needs and costs about $60,000. The second dd80 should be installed about 1 October 1971. Our operations depend on the dd80, and at present we are moving the dd80 plug from the 6600 to the 7600 as needed. Robertson added that we would like to get a plotter which has 16,000 coordinate addresses in each direction and sells for about $200,000.

H. Other Business

Palmer said the budget for FY 1972 will be at the same level as FY 1971, except there will be a net decrease in personnel. A special request to NSF must now be made for each additional staff member.
Lavoie asked if the programming techniques of in-house and non-NCAR users were scrutinized to the same extent. He suggested that some review process be set up for all problems exceeding some machine time limit, so that the computing techniques of all users are reviewed to the same extent.

Palmer said one difference between non-NCAR and in-house users is that in-house users' problems tend to continue whereas non-NCAR projects have a definite termination. Hildebrandt said a fair amount of control over in-house programs is effected because most of the programming is done by Computing Facility programmers. Leith added that the monthly computer usage summaries are reviewed by the staff and if, for example, PP is exceeding CP, that scientist is questioned about it. He said there is a certain amount of pressure exerted in-house for good programming.

The meeting was adjourned at 5:15 p.m. The next meeting will be held on 1 November 1971.
Table 1. Projection of computing time requirements of GCM group for various problems in units of the total operation of one CDC 6600 per year

<table>
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<th>Problem/FY</th>
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<td>10. GDP</td>
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* The entire GCM development program at NCAR is intimately related to GARP. The asterisks identify those items in the program which are essential to GARP preparations and operations in the next two years. All of the remaining projects will interact with the GARP data, and it is essential that significant progress be made on these projects prior to the commencement of FGGE.
NCAR
PROJECTION - COMPUTER USAGE
FY 1971 - 76

GCM = General Circulation Models
and Associated Work
T & C = Turbulence and Convection

Lines Show Power

UNITS AVAILABLE (1 UNIT = POWER OF CDC 6600)

FY71 FY72 FY73 FY74 FY75 FY76

OTHER

6600 2.0 1.5 1.0 0.5

GCM 1.4 2.0 3.0 3.5

7600 1.2 2.5 5.0

UNIVERSITY

T & C

ILLIAC

STAR

55.0

25.0

50.0

90.0

90.0
TABLE 3
COST EFFECTIVENESS OF COMPUTERS

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<th>Million ops/sec</th>
<th>Bits/Word</th>
<th>&quot;Power&quot;</th>
<th>Price SMillions</th>
<th>Installation Cost SMillions</th>
<th>Total SMillions</th>
<th>ops/5 Yrs</th>
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<tr>
<td>CDC 7600</td>
<td>27.5</td>
<td>303</td>
<td>3.30</td>
<td>60</td>
<td>7.9</td>
<td>7.9</td>
<td>0.33</td>
<td>8.23</td>
<td>2.60x10^14</td>
<td>31.6</td>
</tr>
<tr>
<td>TI ASC XI</td>
<td>60.0</td>
<td>60</td>
<td>16.67</td>
<td>32</td>
<td>40.0</td>
<td>10.0</td>
<td>0.2</td>
<td>10.2</td>
<td>1.31x10^15</td>
<td>128.0</td>
</tr>
<tr>
<td>TI ASC X4</td>
<td>60.0</td>
<td>15</td>
<td>66.67</td>
<td>32</td>
<td>160.0</td>
<td>14.0</td>
<td>0.25</td>
<td>14.25</td>
<td>5.26x10^15</td>
<td>369.0</td>
</tr>
<tr>
<td>BURROUGHS ILLIAC IV (I quadrant)</td>
<td>67.0</td>
<td>10.5</td>
<td>95.00</td>
<td>32</td>
<td>227.0</td>
<td>15.0</td>
<td>2.5</td>
<td>17.5</td>
<td>7.49x10^15</td>
<td>428.0</td>
</tr>
<tr>
<td>CDC STAR</td>
<td>40.0</td>
<td>10</td>
<td>100.00</td>
<td>32</td>
<td>240.0</td>
<td>10.0</td>
<td>0.3</td>
<td>10.3</td>
<td>7.88x10^15</td>
<td>765.0</td>
</tr>
</tbody>
</table>

Footnote: In Table 3 we have attempted to estimate the cost effectiveness of a number of machines from the 6600 through the STAR. The machines are arranged in the table in order of increasing cost effectiveness.

The sample computation used to create these estimates is component by component vector multiplication, C(i) = A(i)*B(i), which can be represented by the following couplet in Fortran:

```
DO I = 1,N
    C(i) = A(i)*B(i)
```

This computation can be considered a portion of the computation of the inner product of two vectors (although it would not normally be programmed this way in Fortran).

The column headed million operations per second indicates the rate at which results are formed when the machines are operating at maximum speed in this computation. A single result is a single component of the result vector C.

The column headed power is the ratio of the speed of the machine under consideration to the 6600 in this computation.

In the columns headed price and installation cost, the figures for the 6600 and the 7600 are those for the NCAR machines. Those for the array processing machines are the current manufacturers' estimates of purchase prices and NCAR's estimates of installation cost.

In figuring cost effectiveness of these machines we have arbitrarily assumed that the useful life is five years and that the average speed of execution, even for doing repeatedly this very simple computation, is 1/2 the calculated speed. For cost we consider only the capital expenditure for purchase and installation, and do not attempt to estimate the maintenance and staffing charges. Cost effectiveness is given in millions of operations per dollar of capital expense; the cost effectiveness ratio is the ratio of operations per dollar for the machine under consideration to that figure for the 6600.
### TABLE 4

**BUDGET PROJECTIONS**

*(in thousands)*

<table>
<thead>
<tr>
<th></th>
<th>Actual FY'71</th>
<th>Planned FY'72</th>
<th>Projected FY'73</th>
<th>FY'74</th>
<th>FY'75</th>
<th>FY'76</th>
<th>FY'77</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Salaries &amp; Benefits</strong></td>
<td>885</td>
<td>1,019</td>
<td>1,087</td>
<td>1,300</td>
<td>1,720</td>
<td>2,230</td>
<td>2,660</td>
</tr>
<tr>
<td><strong>Materials &amp; Supplies</strong></td>
<td>126</td>
<td>158</td>
<td>166</td>
<td>250</td>
<td>300</td>
<td>350</td>
<td>390</td>
</tr>
<tr>
<td><strong>Purchased Services</strong></td>
<td>657</td>
<td>2,689</td>
<td>1,636(a)</td>
<td>800</td>
<td>1,100</td>
<td>1,400</td>
<td>1,500</td>
</tr>
<tr>
<td><strong>Miscellaneous</strong></td>
<td>19</td>
<td>15</td>
<td>16</td>
<td>25</td>
<td>35</td>
<td>42</td>
<td>50</td>
</tr>
<tr>
<td><strong>Operations Subtotal</strong></td>
<td>1,687</td>
<td>3,881</td>
<td>2,905</td>
<td>2,375</td>
<td>3,155</td>
<td>4,022</td>
<td>4,600</td>
</tr>
<tr>
<td><strong>Capital Expenditures</strong></td>
<td>111</td>
<td>3</td>
<td>6,518(b)</td>
<td>10,700(c)</td>
<td>250</td>
<td>300</td>
<td>350</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,798</td>
<td>3,884</td>
<td>9,423</td>
<td>13,075</td>
<td>3,405</td>
<td>4,322</td>
<td>4,950</td>
</tr>
<tr>
<td><strong>Staff</strong></td>
<td>63</td>
<td>61</td>
<td>63</td>
<td>78</td>
<td>100</td>
<td>120</td>
<td>130</td>
</tr>
</tbody>
</table>

**Notes**

(a): Includes 6 months' rental of CDC 7600.

(b): Includes purchase of CDC 7600 on January 1, 1973 at a price of $5,918,000, plus $600,000 for high-speed drums.

(c): Includes purchase of CDC STAR ($10 million), installation of STAR ($300K), and on-line storage device ($400K).

*Convert 7600 to purchase. Add drums.*

*Add on-line mass store. Commence site preparation for STAR/ILLIAC.*

*Install STAR/ILLIAC.*
Figure 2

7600 CUMULATIVE EXPENDITURES (IN MILLIONS)

- Break Even Points

Purchase at Year
- 10.77 4 YEARS
- 11.85 4 YEARS
- 11.39 3 YEARS
- 9.77 3 YEARS
- 10.52 3 YEARS
- 9.17 3 YEARS

Purchase Cost
- $6.43 2 YEARS
- $3.82 2 YEARS
- $5.06 2 YEARS
- $6.96 1 YEAR

Assume
1. Maint. Rate Constant
2. Interest on Capital excluded
3. No Price Reduction
4. No Configuration Change

FRACTION OF INITIAL PURCHASE COST

LEASE EXPENDITURE

FY72 FY73 FY74 FY75 FY76 FY77 FY78