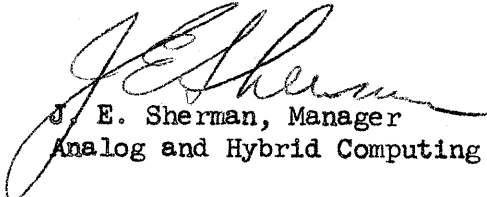


A DISCUSSION OF PROPOSALS BY VENDORS FOR THE HYBRID
SIMULATION EQUIPMENT WHICH IS TO BE INSTALLED IN
BLDG. 181 FOR THE C-3 PROJECT

On March 25, 1966, J. E. Sherman, Manager of Analog and Hybrid Computing, made a presentation on the selection of a vendor for the Hybrid Computing Center to some 40 LMSC people including representatives from the C-3 Project Office, Information Processing, MSD Facilities, Procurement, and Dynamic Analysis and Simulation.

The presentation was in the form of a discussion accompanied by a set of charts. The charts plus a transcription of the discussion follows. It must be remembered that this is a literal transcription and is intelligible only in conjunction with the charts. It may be that the grammatical construction of the accompanying text is sometimes inadequate because this is a literal transcription.


J. E. Sherman, Manager
Analog and Hybrid Computing

HYBRID COMPUTER SYSTEM

Chart No. 1

The purpose of this meeting is to discuss how we selected a hybrid computer system for use on the C-3 Project. First, I would like to introduce to you the people who worked on the project. Tom Anderson, Ken Bedient, Dee Foote, and Ralph Wheeler. These people have been working on this project since last November. The first thing they did was to prepare a Request for Proposal which was sent to various vendors. They have done an excellent job on this document. It is quite detailed and quite complete. We have received a number of favorable comments from the vendors who have examined it.

As a sample of the kinds of replies we got, I've selected replies from three of the vendors and brought those along. Electronic Associates, Inc., Astrodata, and Beckman. This gives you some idea of the magnitude of the work of evaluating these proposals.

HYBRID SYSTEM

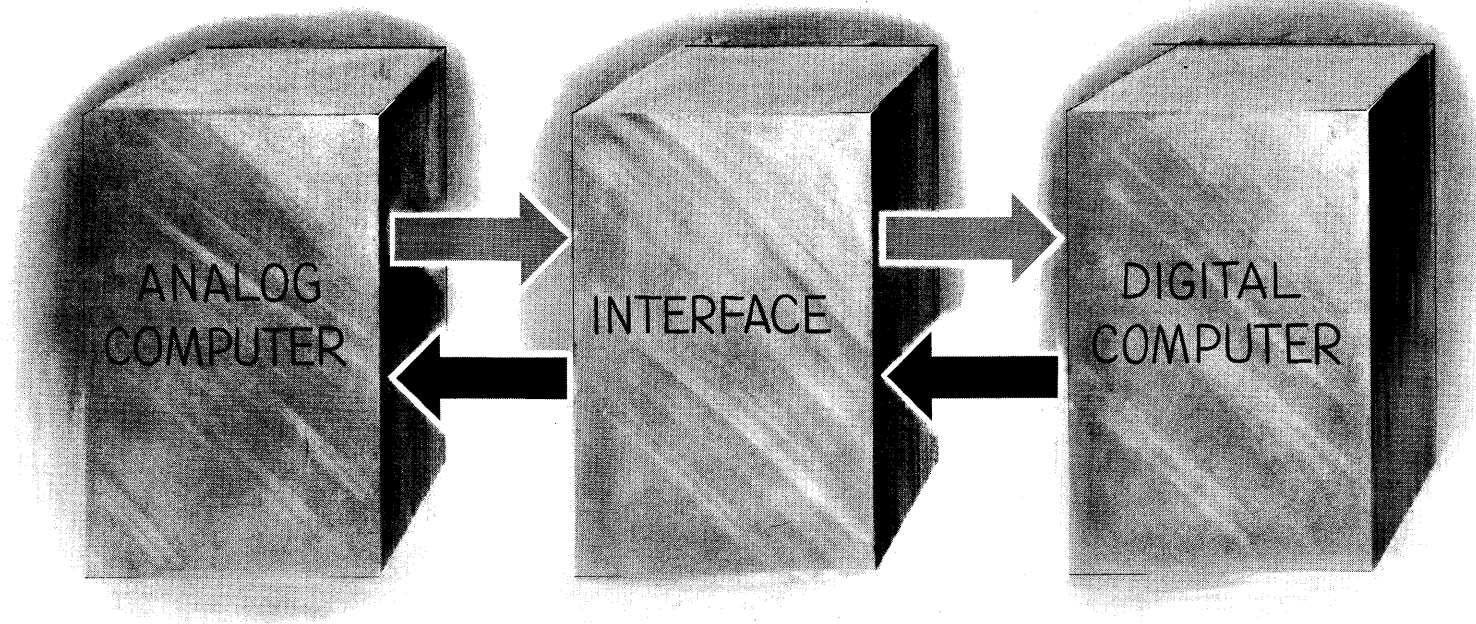


Chart No. 2

First, I think I should tell you what a hybrid computer is. A hybrid computer is composed of an analog computer, an interface system, and a digital computer. What we have to do is to constrain these three diverse pieces of equipment to work as a single system.

HYBRID SYSTEM CONFIGURATION

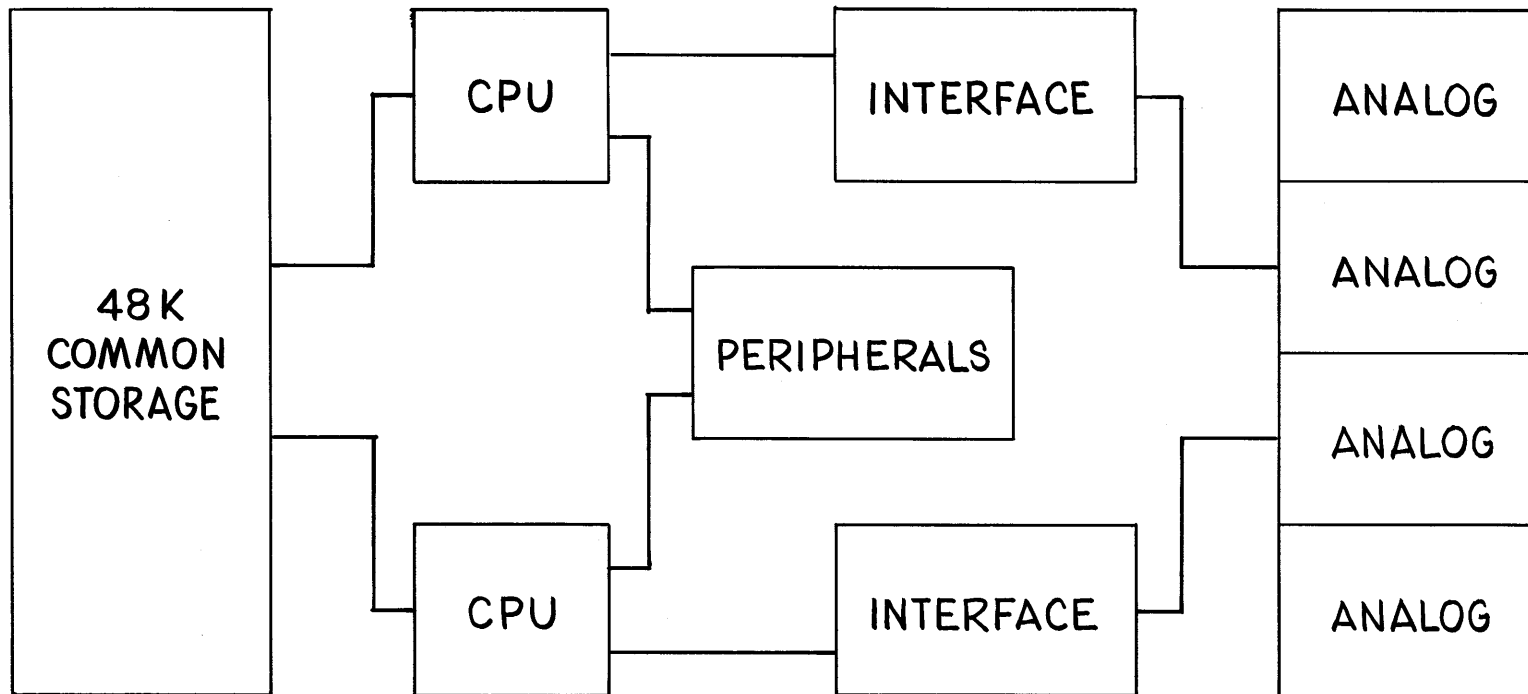


Chart No. 3

The particular hybrid system that we have conceived to handle the problem posed by the C3 Project consists of two central processing units connected to a common core storage of approximately 48,000 words. They are connected to the normal digital peripheral equipment, two pieces of interface equipment and four analog computers.

LMSC'S HYBRID COMPUTER SYSTEM

REQUEST FOR PROPOSAL

BIDS RECEIVED

ASTRODATA INC (COMCOR)
APPLIED DYNAMICS INC.
BECKMAN INSTRUMENTS
CONTROL DATA CORP.
ELECTRONIC ASSOCIATES INC.
INTERNATIONAL BUSINESS
MACHINES
MILGO ELECTRONIC CORP.
RAYTHEON COMPUTER
REEVES INSTRUMENT CO
SPERRY RAND CORP (UNIVAC)

NO BID

ADAGE INC
COMPUTER CONTROLS CO.
DIGITAL EQUIPMENT CORP.
G.P.S. INSTRUMENT CO.
SCIENTIFIC DATA SYSTEMS

Chart No. 4

We sent bids to 15 different companies. Of the 15 companies, five of them did not reply and ten replied.

RESPONSES TO LMSC'S RFP

ASTRODATA (COMCOR) _____ SEVERAL HYBRID SYSTEMS _____ MEETS ALL MAJOR REQMTS

APPLIED DYNAMICS _____ AD 256 ANALOG ONLY _____ DID NOT MEET OUR REQMTS

BECKMAN _____ 2200/SDS 9300 HYBRID _____ MEETS ALL MAJOR REQMTS

CONTROL DATA _____ 3300 DIGITAL+ADCOM INTERFACE _____ SAME OFFERED WITH ASTRODATA

ELECTRONIC ASSOCIATES _____ 8900 HYBRID SYSTEM _____ MEETS ALL MAJOR REQMTS

IBM _____ 360-44 DIGITAL ONLY _____ DELIVERY TOO LONG

MILGO _____ 4100 ANALOG ONLY _____ DID NOT MEET OUR REQMTS

RAYTHEON _____ 520 DIGITAL ONLY _____ TOO SLOW FOR OUR REQMTS

REEVES _____ 600/SDS 9300 HYBRID _____ DID NOT MEET OUR REQMTS

UNIVAC _____ 494 DIGITAL ONLY _____ DELIVERY TOO LONG

Chart No. 5

Of the ten companies who replied, it was soon apparent that three of the bids were vastly superior to the others. Those were the bids sent in by Astrodata, Beckman, and EAI. The other bids were simply not responsive to our Request for Proposal in one or more major requirements. Applied Dynamics bid on the analog portion of the system and they bid their standard Analog Computer, and did not really follow the particular requirements which we put forth in our Request for Quotation.

Milgo, which is a new entry into the analog computer field, makes a very interesting analog computer, but they felt they did not want to enter a serious bid at this time. They are in the process of changing from a few specially built systems to a standard line of analog computers, and they are simply not ready at this time. The Reeves Company, one of the old timers in the analog computer industry, has come out with a brand new analog computer, and they did bid their computer in conjunction with SDS digital computer, but unfortunately, the Reeves computer is just too new at this time and is not well enough established. Further, they bid their standard computer system which again was not in line with our requirements. Both IBM and Univac bid on the digital portion and both of them had rather interesting digital computer systems -- particularly the IBM 360144 -- but unfortunately, the delivery date is much too long. Raytheon bid on the digital computer portion, but the computer was too small and too slow to meet our basic requirements. CDC bid a 3300 digital computer and they also bid an interface made by their subsidiary, Adcomp. The 3300 digital computer is also included as a sub-bid in the Astrodata system. We had previously evaluated the Adcomp interface, and it simply was not as good as the interface system offered by the other people.

MAJOR ELEMENTS IN AN ANALOG SYSTEM

- BASIC CONSOLE
 - EDVM
 - SCOPE
 - RCVD
 - ETC.
 - 60 INTEGRATORS
 - 60 SUMMERS
 - 90 MULTIPLIERS
 - 6 RESOLVERS
 - 24 CARD SET FUNCTION GENERATORS
 - 30 LIMITERS
 - COMPARATORS
 - ELECTRONIC SW
 - RELAYS
 - 240 POTENTIOMETERS
 - 200 LOGIC UNITS
 - 3 EIGHT CHANNEL RECORDERS
 - 3 X-Y PLOTTERS
-
- SHARED BY THE FOUR ANALOG COMPUTERS
 - TEST RACK
 - I/O SYSTEM
 - SPARE PARTS

Chart No. 6

Now, I want to point out to you the major elements in an analog computing system. There are four of these analog systems in the overall hybrid computer system. Each of the four consists of a basic console, that is the control console which contains a digital voltmeter, oscilloscope, a remote control voltage divider, and other pieces of equipment to operate the system. It has, for example, the readout selector switch and things of that nature. In active components, they have approximately 60 integrators, 60 summing amplifiers, 90 multipliers, 6 resolvers, 24 function generators, 30 limiters, 240 potentiometers, 200 logic units, (3) 8-channel strip chart recorders, and 3 x-y plotters. Now, contained in the non-linear equipment, is another 300 inverting amplifiers. In addition we have an adequate quantity of miscellaneous equipment such as comparators, electronic switches, relays, function switches, and things of a like nature. The logic units are something that are fairly new to the analog computing field. These are flip-flops, gates -- devices of this nature. In addition to the equipment which is in each of the four analog computers, there is another group of equipment which is shared by all of the four machines, namely, the test rack for maintenance purposes, an I/O system which will be used when the digital computer, which is part of the hybrid system is not available, and the spare parts necessary to maintain the system.

PERFORMANCE COMPARISON OF ANALOG SYSTEMS

	ASTRODATA CI 5000	BECKMAN 2200	ELECTRONIC ASSOC. 8800
● AMPLIFIER	1	2	3
● MULTIPLIER	2	2	1
● RESOLVER	2	3	1
● CARDSET FUNCTION GENERATOR	1	2	1
● LOGIC	2	3	1
● I/O SYSTEM	1	2	3
● CROSSTALK	1	2	1
● DRIFT	1	2	1
● CONSTRUCTION	2	3	1
● MAINTAINABILITY	2	3	1
MEAN	1.5	2.4	1.4

Chart No. 7

Now for a performance comparison of the analog portion of the bids put out by the three major bidders. This is really a subjective addition of a series of objective tests and examinations. The detailed specifications are quite difficult to describe to a large group -- mainly, they are in the form of graphs and plots -- so we have merely given a summation at this point. For example, when we evaluated the amplifiers, we looked at such things as the total error curve as a function of frequency; the change in amplitude as a function of frequency; the change in phase angle as a function of frequency; the noise level; the output impedance, and various other characteristics and qualifications. The summation of all these indicate to us that the amplifier offered by the Comcor subsidiary of Astrodata is the best of the three; the Beckman amplifier being second best, and EAI coming out third best. Now this is rather surprising because EAI is, after all, the leading manufacturer of analog computers, has been for some time. They have recently redesigned their analog computing system. The 8800 is the latest development in that line, and it has involved a complete redesign of the computer and all the components in it, including the amplifier. According to the test data furnished to us by EAI, and supplemented by additional measurements which we have made ourselves, they just seem to have made a blunder when they designed the amplifier. Their total error at 8 cycles is .2 volts. Now that's more than double the error at that frequency, or any nearby frequency, of any of the competitors. The output impedance is much higher than that offered by its competitors. The frequency response is not as good. In talking these matters over with EAI's technical representative, we learned that they plan to redesign the amplifiers some time this year. They know it isn't quite right, and they are going to do something about it, but we don't know at this time exactly what it is they are going to do or how well it's going to turn out. However, in multipliers and most of the rest of the items, EAI comes out in first place. One exception being the I/O system. Now the basic I/O system that EAI offers with their analog computer is very good. It is a small digital computer. But, since we are buying this as part of a hybrid system, we will have fairly large digital computers that will be available for the I/O work most of the time. However, when they are not available, we would like some kind of an automatic I/O system to the computers. However, it can be fairly simple -- a punch paper tape reader that will enable us to set potentiometers, turn the computer on and off, and a few simple things like this. EAI just does not have anything adequate in the small area. The only thing they can offer us is the small digital computer costing some forty thousand dollars. Both of the other people are able to offer us adequate items for much less money. In everything else, EAI comes out in first place. The Comcor equipment offered by Astrodata comes out either tied with EAI or following them very closely in second place. Beckman comes out either second or third in all regards. This is primarily because the Beckman computers have been designed a number of years ago

Chart No. 7 (con'td)

and are really obsolete when compared with the units offered by the other two people. Now, if we take the mean of the subject ratings, we come up with a subjective overall performance index, and this shows that EAI, if we can somehow overcome the major difficulties in the amplifier, is probably the best of the analog computers. However, they are rather closely followed by Comcor/Astrodata -- Beckman comes in a fairly poor third.

INTERFACE FUNCTIONAL BLOCK DIAGRAM

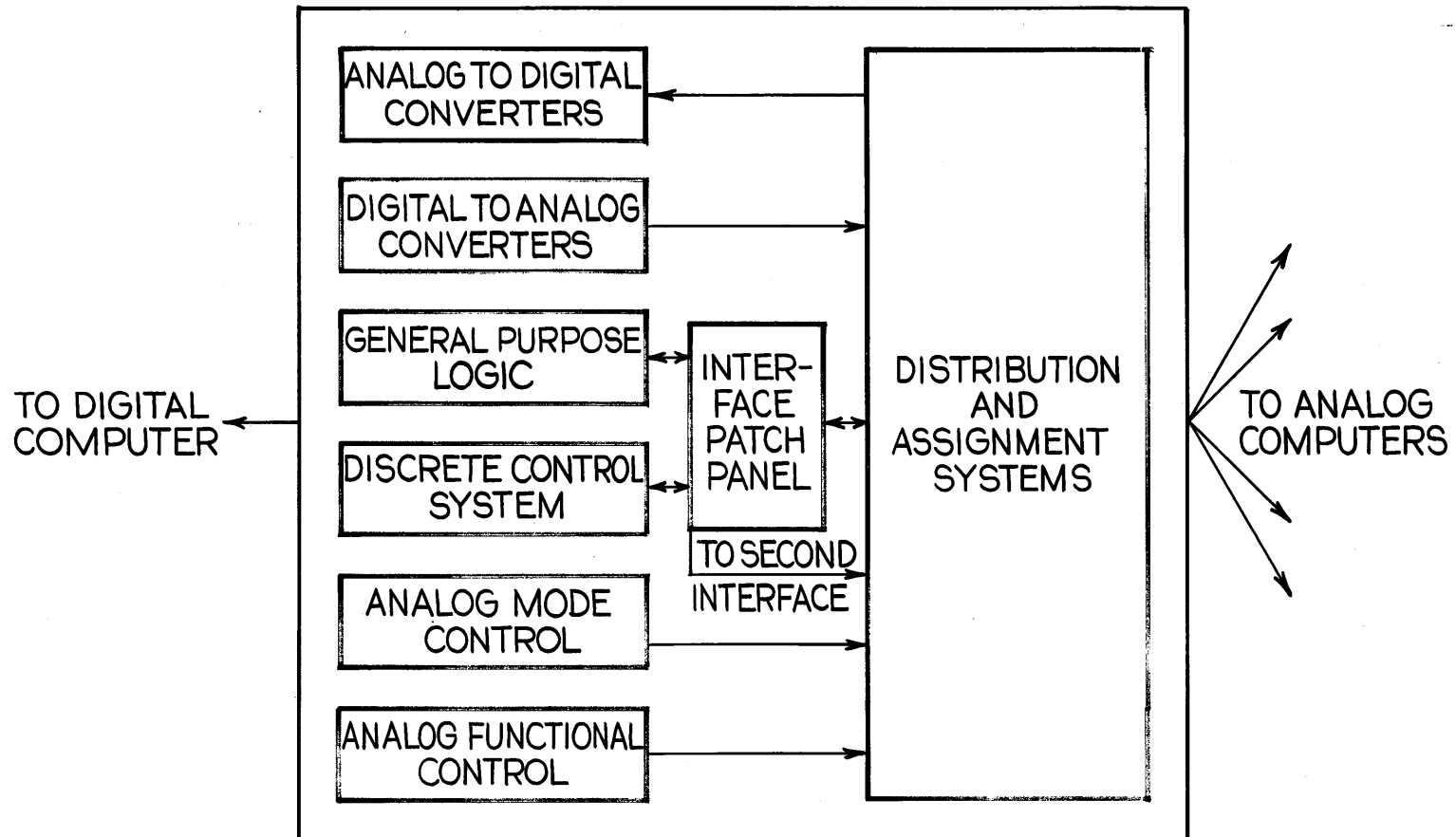


Chart No. 8

Now the interface part of the hybrid system is a little more complex than you might at first think. When you say interface, most people say, oh well that is just some A-D converters, and some D-A converters. Most certainly the A-D converters and D-A converters are a basic necessity to any interface. But in addition to that, we feel you must have some general purpose logic as part of the interface system. Now, this is necessary to control the signal flow between the digital and analog computers. It is also necessary to supplement the amount of logic which is presented on the analog computers. In the problems that we are considering for this particular system, that logic on the analog computers is simply not adequate. It also contains a discrete control system which controls the signals going back and forth between the computers. Actually it enables one computer to communicate and control the other. There is also the analog mode control. Now this enables the digital computer to control the mode of the analog computer -- that means hold, pot set, integrate, and so on. This is also the analog functional control. This enables the digital computer to do such things as set potentiometers, readout amplifiers, and so on. In order to make proper use of all this equipment, we think that there should be a patchpanel on the interface. Now this enables us to make proper use of the logic and to correctly and efficiently monitor and direct the discrete control system. The other function of the interface is the distribution and assignment of the signal flow between the analog computers and the digital computers. We want to have some flexibility and not have one analog computer always tied to a single digital computer. There may be reasons for putting three analog computers with one digital computer or even all four of them with one digital computer.

ANALOG TO DIGITAL CONVERSION SYSTEM

	TRANS- MISSION RATE/16CH (μ SEC)	ERROR (%R)	RESOLU- TION (NO. BITS)	S/H DECAY (μ V/ μ SEC)	S/H RECOVERY (μ SEC)	LOGIC CONTROL	CHANNELS WITH S/H (TOTAL)	MUX CHANNELS (TOTAL)	ASSIGN- MENT CAPABILITY	RATING
ASTRODATA (COMCOR)	162	.0232	15	2	40	G	32	128	G	1
BECKMAN	488	.025	15	10	80	G	40	120	E	3
EAI (1)	309	.04625	14	33	40	P ₁	64	128	P ₂	2
EAI (2)	309	.04625	14	33	40	P ₁	32	64	P ₃	4

E EXCELLENT
 G GOOD
 S SATISFACTORY
 P_i POOR

P₁ S/H AMPLIFIERS CAN NOT BE DIRECTLY
 CONTROLLED FROM INTERFACE OR ANALOGS
 P₂ "J" BOX
 P₃ HARDWIRED

Chart No. 9

Now let's examine some of the technical features of the interface. In particular, the analog-digital conversion system. We are interested in such things as transmission range, this is the time in microseconds it takes to transmit the data on 16 channels from analog to digital. The times given the Astrodata system are quite a bit faster than the other two. The error as given here is a percent of reference. Both Astrodata and Comcor are quite good, maybe twice as good as EAI. The resolution, that is the number of bits in a converter, two of them at 15, two at 14. Sample and hold decay is measured in microvolts per microsecond, and we would like to have a small number here so that it decays slowly; Astrodata at 2, Beckman at 10, and EAI at 33. The sample and hold recovery time in microseconds -- we want this to be a small number. We want it to recover rapidly. Astrodata and EAI at 40 and Beckman at 80. Logic control -- we think that both Astrodata and Beckman are quite good. EAI is rather poor. This is primarily because in the EAI system, the sample and hold amplifiers cannot be directly controlled from the interface or from the analog computers, but only from the digital computer. This puts some limitation on our programming ability. Now we have the total number of channels which have sample and hold amplifiers. We are talking about the total number on both systems. We have 32, 40 and 64. We requested 32. The Beckman units come in groups of 10, so they took the next largest module that they make. EAI offered us 64 because they claim that for them it was cheaper to offer us double the number rather than build flexibility into their two interfaces. What we requested was that unused sample and hold channels from one interface could be borrowed and used by the other interface. They did not have this flexibility. Instead, to make up that requirement, they said "we will offer you twice as many". In their second system, they offered us 32. Incidentally, the reason we had the two EAI systems here is that they actually sent in two bids. The first bid was very responsive to our Request for Proposal, but they felt that the overall price was kind of high, so they sent in an unsolicited second bid which is closer to their standard system. It doesn't have some of the things we want, but we certainly felt we should consider it. The next channel shows the total capacity of the multiplex system. Now, not all of these channels are currently available, but this is the size of the multiplexer available for ultimate expansion and you see that the three systems are roughly comparable, with some limitations on EAI's second system.

Assignment Capability- Now this is the ability to route analog signals to the two digital computers. This gives us flexibility as to which computer is used with which analog machine. The Beckman system was excellent in this regard. The Astrodata system was very good. EAI was poor. This is because in the system they have here, the only way you can do this is by plugging and unplugging cables on what they call a configurator panel. The other two do this by switches and electronic circuitry. The other EAI system has no flexibility at all. Certain digital computers are permanently wired to certain analog computers. It seems that EAI, when they conceived of the hybrid system, conceived of one digital computer working with one or more analog computers, but they never thought that anyone would want a system involving two digital

Chart No. 9 (con'td)

computers, hence the lack of flexibility in this area. When we look at the overall picture and make a comparison rating of the systems offered by the various competitors, we find Astrodata on top, with the first EAI system second, the Beckman system third, and the other EAI system fourth.

DIGITAL TO ANALOG CONVERSION SYSTEM

INTERFACE

	TRANSMISSION RATE / 32 CHAN. (μ SEC)	ERROR (%R)	RESOLUTION (TOTAL BITS)	ANALOG COMPATABILITY	AMPLIFIER RECOVERY TIME (μ SEC)	LOGIC CONTROL	LOCAL CONTROL	CHANNELS (TOTAL)	ASSIGNMENT CAPABILITY	RATING
ASTRODATA/COMCOR	370	.014	15	G	50	S	G	64	G	1
BECKMAN/SDS	508	.02	15	G	300	S	G	60	E	3
EAI (1)	367	.025	14	S	50	S	P ₂	64	P ₃	2
EAI (2)	367	.025	14	S	50	P ₁	P ₂	64	P ₄	4

E EXCELLENT
 G GOOD
 S SATISFACTORY
 P₁ POOR

P₁ NO INDIVIDUAL OVERRIDE CONTROL
 P₂ DATA CAN NOT BE LOADED WITHOUT THE USE OF THE DIGITAL COMPUTER
 P₃ 'J' BOX
 P₄ HARDWIRED

Chart No. 10

Now we look at the digital to analog conversion system. Again we are interested in transmission rate. Now this is the time taking to transmit the data on all 32 channels, and it is measured in microseconds. Beckman is slow compared to the other vendors. Error as a percentage of reference - this is the overall through put error. Astrodata is a little better than the others. Resolution, total number of bits -- again Astrodata and Beckman working with 15 bit units - EAI with a 14 bit unit.

Analog Compatibility - We rate Astrodata and Beckman both good, and EAI satisfactory. This is because both of these companies use computing amplifiers for the output amplifier of the digital to analog converter. EAI uses an amplifier supplied by Adage. It has different characteristics. It doesn't have as much current output. It doesn't have as low an output impedance, and various other characteristics. Analog recovery time is in microseconds. Beckman is quite a bit higher than the others.

Logic Control - They are all satisfactory, except the second EAI system. Now this is because that system does not allow any individual override control of the digital computers -- which puts some limitations on our programming ability.

Local Control - Astrodata and Beckman are good. EAI is poor. This is because in the EAI system, data cannot be loaded into the DAC's without the use of the digital computer. Now when the problem is running normally, this is no limitation, but during the trouble shooting phase and for maintenance operations, this would be a serious handicap.

Total number of channels - Everyone is in the 60's.

Assignment Capability - This is the same sort of thing we talked about on the other chart. Again the same types of ratings for the same reasons. When we rate the vendors on their digital to analog converting systems, we find that Astrodata is in first place, EAI second, Beckman third and EAI fourth. It's the same as the previous chart.

GENERAL PURPOSE LOGIC

	QUANTITY (LOGIC UNITS)	TYPE (SYNC. OR ASYNC)	BASIC LOGIC FREQ. (MP/S)	CLOCK FREQ. (MP/S)	LOGIC CONTROL AND MONITORING	RATING
ASTRODATA/COMCOR	454	BOTH (1 MP/S)	1	0.1	S	2
BECKMAN (SDS)	526	ASYNC	.5	0.1	S	3
EAI (1)	514	SYNC (2 MP/S)	20	0.1	E	1
EAI (2)	0	—	—	—	—	4

E - EXCELLENT
 G - GOOD
 S - SATISFACTORY

Chart No. 11

Now I want to talk to you about the general purpose logic which is on the interface. The quantities are all adequate for our purposes. The type of logic could be either synchronous or asynchronous. Astrodata offers us the option of having both synchronous and asynchronous logic. That is, we can make a portion of it synchronous, and we can use the rest asynchronously. Beckman offers us only asynchronous logic. EAI offers us only synchronous logic.

Basic Logic Frequency - This refers to the ability of the individual logic elements to respond to a signal. Astrodata works at 1 megapulse per second; Beckman at 1/2 megapulse per second, EAI at 20 megapulses per second. The clock frequency, that is the frequency at which the logic is clocked, in all cases, is 100,000 pulses per second.

Logic Control and Monitoring - EAI is a much better system than that offered by either Astrodata or Beckman. In the second EAI system, they just didn't offer any logic. The comparative rating on this particular element of the interface, EAI is the winner, Astrodata second, and Beckman third.

DISCRETE CONTROL SYSTEM

	SENSE LINES	CONTROL LINES	INTERRUPT LINES	INTERRUPT CONTROL	RATING
● ASTRODATA/COMCOR	136	136	48	G	1
● BECKMAN /SDS	112	112	48	G	2
● EAI (1)	128	128	80	P*	3
● EAI (2)	0	0	0	-	4

* NO MASK CAPABILITY PROVIDED

Chart No. 12

For the discrete control system, we have sense lines, control lines, and interrupt lines, and we have adequate quantities of each. Now the sense lines are used to keep the digital computer informed of the state of the analog problem. The control lines are used to control analog computer functions. The interrupt lines are used to send interrupt signals from the analog computer to the digital computer, and the interrupt control is how we control the interrupt lines. We have to grade EAI poorly here, because they had no masking capability. In the comparative ratings of this particular section, we have to give - Astrodata, Beckman and EAI.

INTERFACE RATING SUMMARY

	ANALOG TO DIGITAL CONV. SYSTEM	DIGITAL TO ANALOG CONV. SYSTEM	GENERAL PURPOSE LOGIC	DISCRETE CONTROL SYSTEM	OVERALL RATING
● ASTRODATA/COMCOR	1	1	2	1	1
● BECKMAN /SDS	3	3	3	2	3
● EAI (1)	2	2	1	3	2
● EAI (2)	4	4	4	4	4

Chart No. 13

In the interface rating summary, we take the quantities we've looked at before and give you a summary chart. In the overall rating for the interface, that's considering the A-D converters, the D-A converters, the general purpose logic, and the discrete control system, in summation we think Astrodata has the best one, EAI the second best, Beckman third, and the second EAI system runs a poor fourth.

DUAL CDC 3300 CONFIGURATION

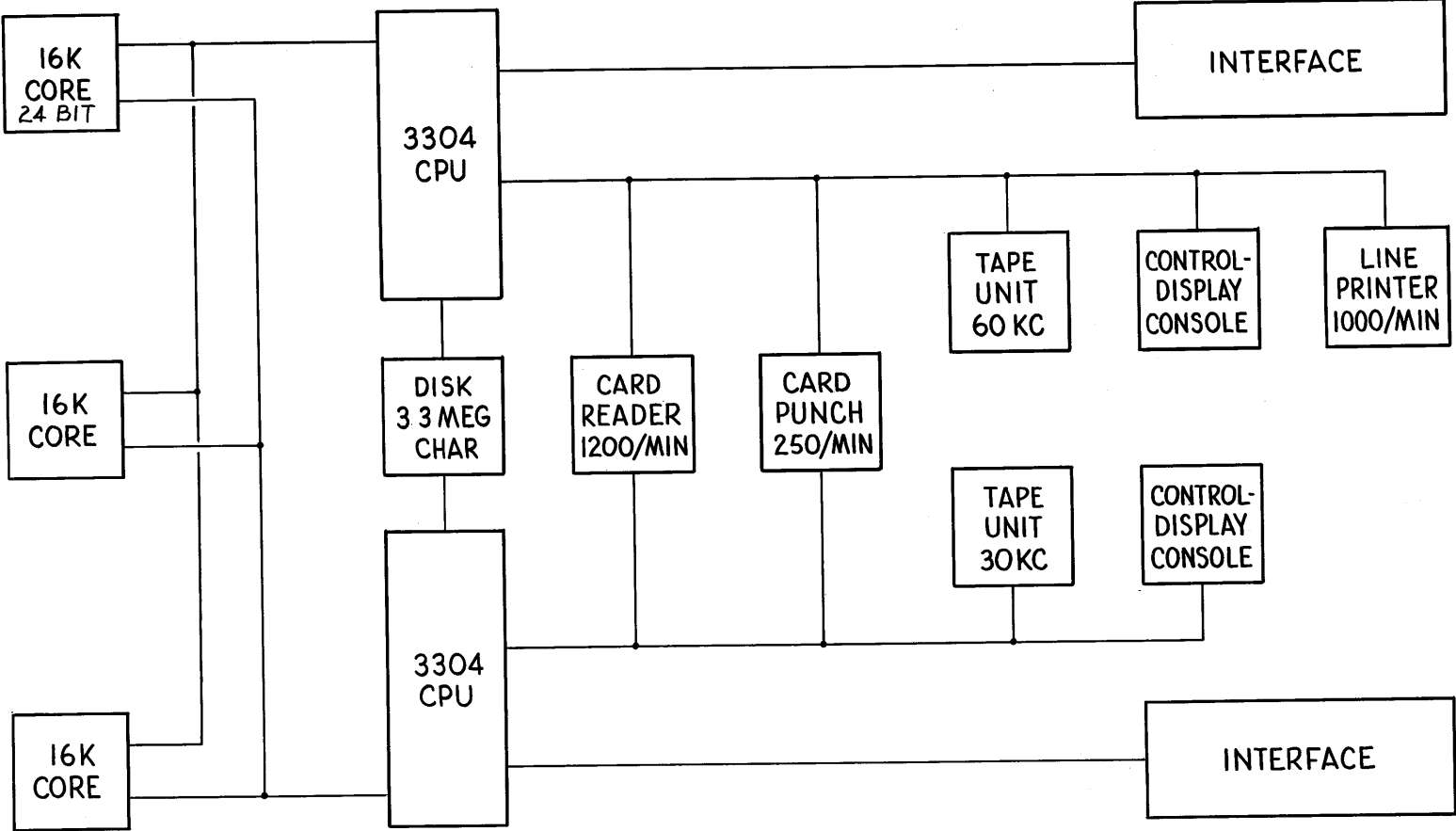


Chart No. 14

Now I will talk about digital computers. The first of these will be the configuration offered for the CDC 3300. This has two central processing units, three banks of core, each bank having 16,000 words, and each word being 24 bits. Each of the CPU's can talk to any or all of the banks of core. They share a disk with 33 million characters and they share the normal digital peripheral units, the card reader and card punch. There are two tape units, one to each CPU, two control display consoles, one to each CPU and the line printer is constrained to operate with only one of the CPU's. Each of the CPU's is connected to an interface which in turn is connected to the four analog computers.

SDS 9300 CONFIGURATION

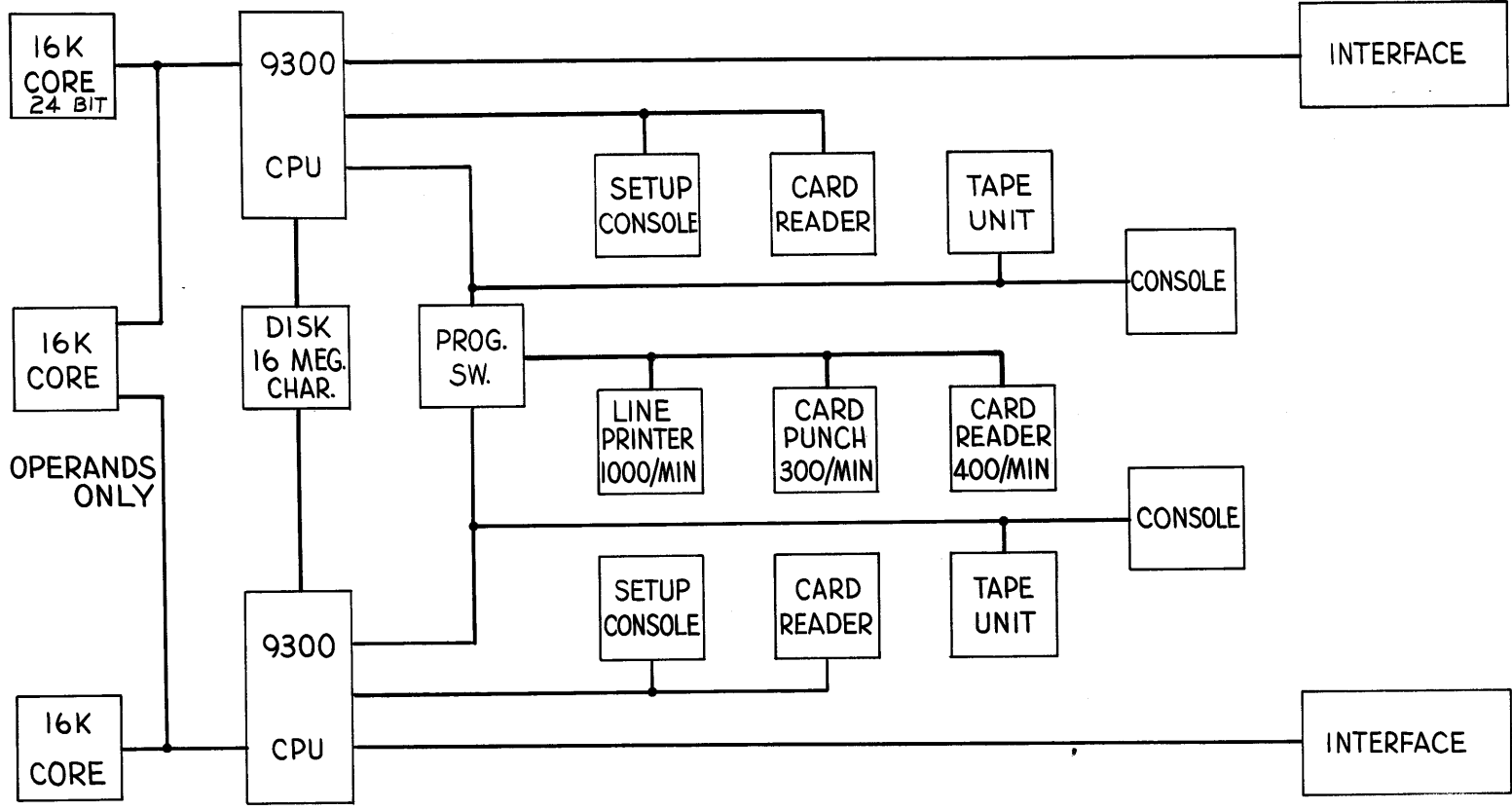


Chart No. 15

On the SDS system 9300 digital computer, again we have two CPU's connected to three banks of core storage. Each of the banks is 16,000 words, they are 24 bit words. However, you will note that this CPU does not have complete ability to talk to both of these banks of core. This CPU has complete freedom to this core, but can use this core for operands only. In no case can either of the CPU's use all three banks of core. It shares a disk of 16 million characters and it shares the peripheral's through a programming switch. Now this enables all of the peripherals to be used by either one computer or the other. You have to actually throw the switch in order to switch them back and forth, and they all switch at the same time. In addition, we have the operational consoles, and a one tape unit to each CPU. Additionally we have set up console and card reader. Now these are smaller items and are made by the Beckman Company for use with the 9300 when its part of their hybrid system. These are specialized read out and control units for hybrid work and there is one set with each CPU. Both of the CPU's are attached to interfaces which are again in turn attached to the analog computers.

EAI 8400 CONFIGURATION

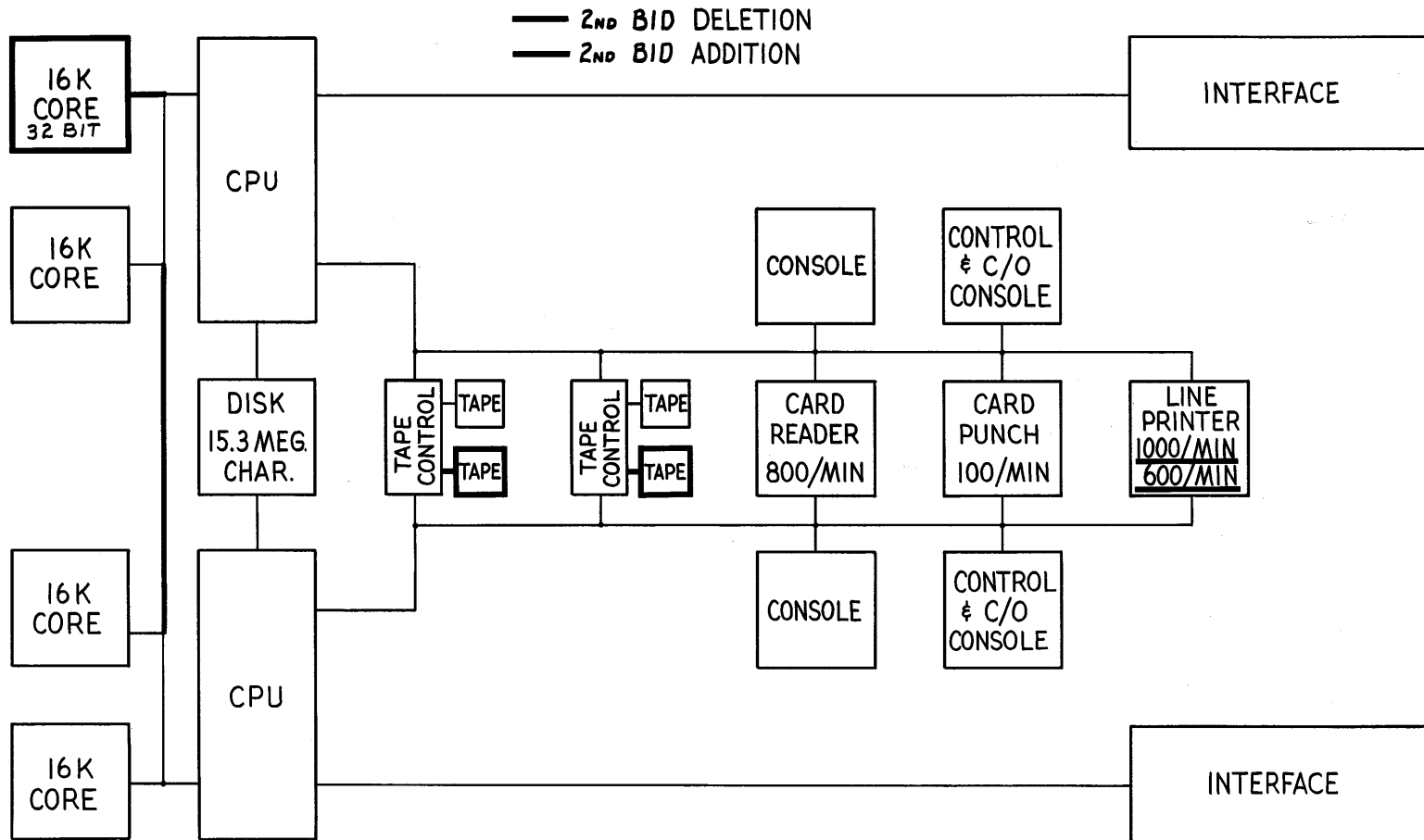


Chart No. 16

Now for the EAI 8400 Digital Computer. Again we have two central processing units. In their first bid, they offered to tie each of the CPU's to two banks of core memory, each bank of memory having 16 thousand words, and the words here have 32 bits. In the second bid, they removed one bank of core, but they did connect the three cores together so that each CPU could talk to all three cores. The two CPU's share a 15 million character disk, and they share the normal digital peripherals, a card reader, a card punch, a line printer, either a 1000 line a minute, or a 600 line a minute printer between the two CPU's.

The original bid had 4 tape units, the second bid removed two of the tape units. We also have the control consoles and the special hybrid control consoles. Each of the units are connected in turn to interfaces which are then connected to analog computers.

CDC 6400 CONFIGURATION

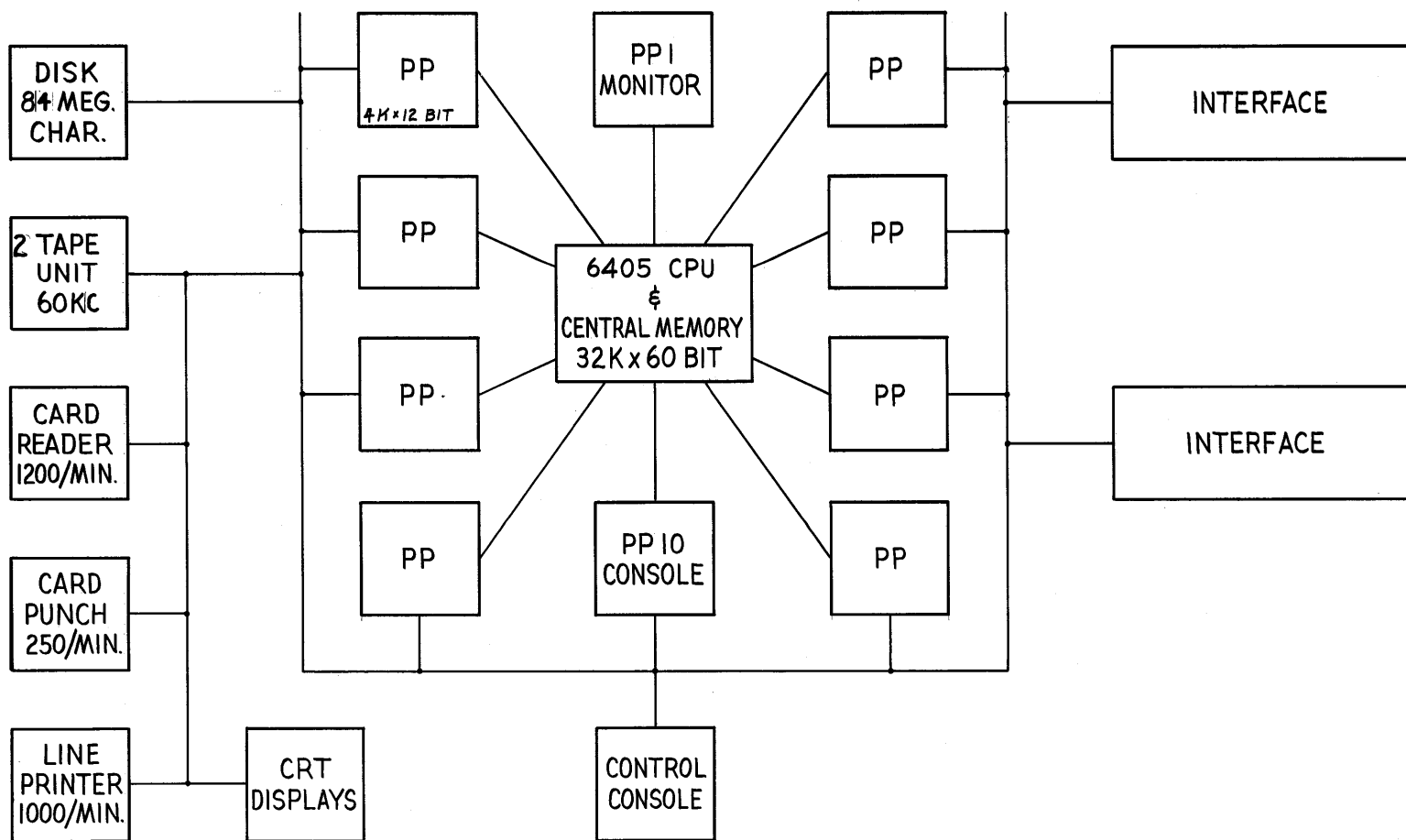


Chart No. 17

Now in the course of evaluating digital computers for the hybrid system, we came across the CDC 6400 computer. This is a change from our original conception of using two central processors. This has a single central processing unit and a single central memory. However, this memory is 32 thousand words and they are 60 bit words. We also have ten peripheral processors which work with the central memory. Each of these peripheral processors has an additional 4 thousand words of memory and they are 12 bit words. We have a set of peripherals and an 84 million character disk, 2 tape units, a card reader, punch and line printer, and we have the cathode ray tube displays and controls. These are remote input/output, on-line control units. We have the main control console. Now, in practice, we would assign four of the peripheral processors to work with the various digital peripheral units, and we would assign another four peripheral processors to work with the two interfaces. One processor would be assigned strictly to the main control console and the other processor would contain the monitor for the overall operation of the system.

The digital computer then is connected to the two interface units which are then connected to the analog computers. Even though we consider a single digital computer, we still kept the concept of two separate interfaces simply because of the size of the units, the amount of equipment in them, and the size of the patchboard.

DIGITAL COMPUTER

	STORAGE			PERIPHERALS			
	SPEED MICRO SEC.	CORE SIZE BITS/K STOR.	DISC MILLIONS CHAR.	TAPE	CARD READER CPM	PRINTER LPM	PUNCH CPM
CDC 6400	1.0	60 x 32K+ 12 x 40K	84.1	2	1200	1000	250
EAI 8400	2.0**	32 x 48K	15.3	2	800	600	100
EAI 8400 1st BID	2.0**	32 x 65K	15.3	4	800	1000	100
CDC 3300	1.3**	24 x 48	33.0	2	1200	1000	250
SDS 9300	1.75	24 x 48*	16.0	2	400	1000	300

* NOT ADDRESSABLE FROM BOTH CPU'S

** SLOWER WHEN STORAGE REFERENCE UTILIZES
RELOCATION HARDWARE

Chart No. 18

Now let's look at some of the performance characteristics of the various digital computers. Let us first look at speed memory cycle time. The speed in microseconds for the 6400 is 1; EAI is 2; and 3300 is 1.3; and SDS 1.75. Now, these units are somewhat slower when storage reference utilizes relocation hardware. This is what is known as a paging system, and it is important when you have more than one central processing unit working with a common memory. You want to protect your memory so that one computer does not write in the other computer's memory. On the CDC 6400, I think it is worth pointing out that the effective cycle time can be reduced to .1 microseconds. This is due to memory overlap techniques which are possible in this machine.

Core size - The 6400 has 60 bit words and there is 32 thousand of them. The peripheral processors have 12 bit words, each of the ten have 4 thousand words for a total of 40 thousand. EAI uses 32 bit words and they have either 65 thousand words or 48 thousand, depending on how many banks of storage we consider. The 3200 has 24 bit words with 48 thousand words and the same for the 9300. However, in the 9300, we must remember that all of the storage is not addressable from both of the central processing units. The disk units associated with the various devices in millions of characters, 84, 15 and 33 and 16. Now we feel that the minimum disk size that we can use is in the neighborhood of 30 million characters, which means we have to either compromise our programs to use these disks, or have additional units quoted by the vendor. This one (6400) seems to be somewhat in excess of our minimum requirements, however, it is the smallest disk that is offered with that particular computer system. We figure two tape units should be adequate for the system that we are contemplating. Standard digital peripherals -- you get what you pay for here.

DIGITAL COMPUTER

	FLOATING POINT			DATA CHANNELS	TIME SHARING CAPABILITY	INTERRUPT CAPABILITY
	ACCUR DEC DIG	SPEED	PROG EXEC. REL 6400			
CDC 6400	14	S+	1.0	12	S+	S+*
EAI 8400	7	S+	2.55	4	S+	S+
EAI 8400	7	S+	2.55	4	S+	S+
CDC 3300	10	S	3.08	8	S+	P
SDS 9300	11	S	4.25	8	P	S+

* MACHINE CONTROLS CPU FROM PP RATHER THAN INTERRUPTS

Chart No. 19

More characteristics of the digital computer. In floating point, the accuracy expressed in decimal digits. We have 14 decimal digits on the 6400, 7 from the 8400, 10 from the 3300, and 11 from the 9300. In floating point speed, they are all satisfactory. Some are somewhat faster than the others. If we take the execution time of a Fortran compiled program, we find that if the Control Data 6400 can do that in a certain length of time, which we designate as 1, it will take the 8400 $2\frac{1}{2}$ times to execute the same program, and the 3300, three times as long and the 9300 more than 4 times as long.

The number of data channels available are 12, 4 and 8. In time sharing capability of the computers, all of them except the 9300 are adequate. In interrupt capability, the 6400 and the 8400 are very good in this regard. The 3300 is not adequate. In the 6400, the peripheral processors act as a buffer between the outside interrupt signals and the central processor.

POWER OF VARIOUS COMPUTERS

RELATIVE TO CDC 6400 vs INTERRUPT FREQUENCY

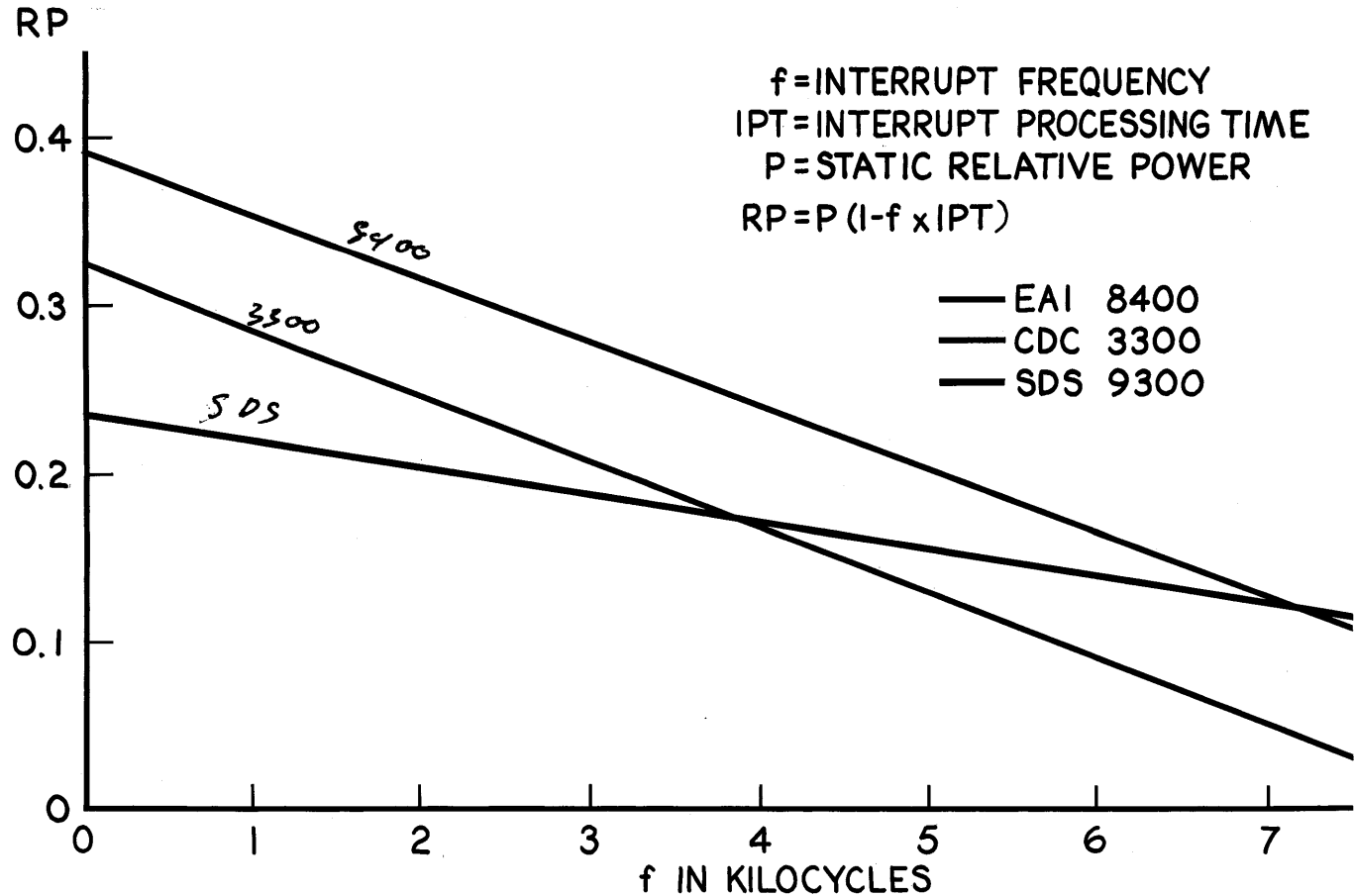


Chart No. 20

Now when we compare the power of the various computers with respect to interrupt processing capability, we come up with some interesting numbers. On this particular chart, we used the 6400 as a base, since it is the fastest of the computers, and if we had the data from the 6400 displayed on this chart, it would be way up here someplace. The number on the scale would be 1.0. The line would go out to the right with a very small negative slope. It would actually intersect the axis out here at around 250 kilocycles.

You can see that the basic speed difference between the 8400 and the 6400 is about $2\frac{1}{2}$ to 1. The difference with the 3300 is about 3-1 and a little under 5-1 for the 9300. When you get out to around 5 kilocycles, which is what we think will be the frequency at which we are commonly processing interrupts, you will see that all of these drop rather drastically, and they all bunch together in an area which indicates that the 6400 is roughly 5 times as powerful as these machines in processing interrupts. Now, it must be remembered that we will have two of these machines in the system, and only one 6400, but even with two of them, it means that the 6400 is now $2\frac{1}{2}$ times as fast in processing interrupts as two each of these computers.

SOFTWARE

	MONITOR	FORTRAN	HYBRID SUPPORT SOFTWARE	APPLICATION SOFTWARE	TIME SHARING	DIAGNOSTICS	DISC ORIENT	SELECTION ORDER
6400 CDC	S	S	P	P	S+	S+	S+	3
8400 EAI	S+	S+	F	S+	S	S	P	1
3300 CDC	P	P	P	P	P	S+	S	4
9300 SDS	S+	S+	G	S	P	S	S+	2

Chart No. 21

A very important consideration in a digital computer system is software -- the availability of it and quality of it -- and when we look at the basic monitor -- we are talking about a real-time monitor here -- we find that they are all satisfactory except the 3300, and we know that isn't satisfactory because we have a 3200 in B/151 and we have had to write our own real-time monitor for it. The Fortran system - They are all satisfactory again except for the 3300. This is not as compatible to existing programs which are now running in Fortran on the 7094 as are the others. We hope that for many cases the digital portion of the hybrid problem which we contemplate doing, that we would be able to make use of at least part of the existing programs which have been written for the 7094. In hybrid support software -- EAI is clearly superior to all of the others. They have put a lot of time and money and effort into this. Now, although none of this software is completely written, debugged, and available today, the program has been underway for more than a year. A large number of people are working at it. We have talked to these people. We have a very high regard for their ability and we're quite positive that the software will be available before the computer is delivered. There is very good hybrid support software for the 9300. This is primarily due to the fact that the Beckman Company, in cooperation with SDS, has been in the hybrid computer market for the past several years. Both of the CDC units are poor in this respect. They do not have any background of hybrid software. In application software, again we are speaking of hybrid application software, the same story holds. Time sharing software, the 6400 and the 8400 are both satisfactory in this regard, particularly the 6400. It was designed for time sharing. The 3300 and 9300 are poor. Diagnostics routines are all satisfactory. Disk oriented software -- they are all alright except the 8400 which, when it was originally conceived, did not contain a disk, and consequently the disk software has not yet been written.

The selection order of the digital computer system based on software, particularly because of the emphasis that we give the hybrid software, EAI is definitely the leader, closely followed by the Beckman-SDS system. The CDC units are third and fourth.

MAJOR EXCEPTIONS

	MAJOR EXCEPTIONS	WEAKNESSES
EAI 8400	FLOATING POINT ACCURACY ONLY 7 DECIMAL DIGITS	CHANNEL SWITCHING UNIT FOR THIS SYSTEM ONLY MEMORY PROTECT SYSTEM FOR THIS SYSTEM ONLY DISC CONTROLLER UNIT FOR THIS SYSTEM ONLY DISPLAY CONTROLLERS UNIT FOR THIS SYSTEM ONLY PERIPHERAL EQUIPMENT OF MANY MANUFACTURERS ALL SOFTWARE PACKAGES UNDER DEVELOPMENT
CDC 3300		FORTRAN INCOMPATIBLE 7094 NO TIME SHARING SOFTWARE AT TIME OF DELIVERY NO APPLICATIONS SUPPORT SOFTWARE
SDS 9300	PROCESSOR CORE ADDRESSING	PERIPHERAL ACCESS POOR NO RELOCATION HARDWARE NON STANDARD CONFIGURATION
CDC 6400		NO APPLICATIONS SUPPORT SOFTWARE*

*ASTRODATA HAS UNDERWAY A COMPANY SPONSORED PROGRAM TO DEVELOP APPLICATIONS SUPPORT SOFTWARE FOR THE 6400. THIS IS A 15 MAN YEAR PROJECT

Chart No. 22

Now let us look at the summation of the major problems associated with each of the digital computers. EAI's unit - Their big problem is floating point accuracy at only 7 decimal digits. The 9300, their big problem is the fact that both CPU's cannot address all the core. There is a limitation on how much core each CPU can address. Other problems, but not quite so significant - in the EAI system - the channel switching unit, the memory protect system, the disk controller unit, and the display controllers unit are offered for the Lockheed system only. This is not their standard hardware. They proposed to do special engineering and develop these units only for us. This causes us some uneasiness because we would much prefer, if at all possible, to buy standard off-the-shelf hardware, that they are going to keep and sell to other people. Then we know that it will be supported in future years and some of the uncertainties are taken out of it. Another thing, the digital peripheral equipment for the EAI computer is obtained from many different manufacturers. Now EAI has entered the digital computer field rather recently, and they make their own main frame and they have designed the system.

They have picked up peripheral equipment from all and sundry. Their printer is made by one company; their tape reader by another, the card reading and punch equipment by still another. We feel that some of the larger digital computer companies who make most or all of their own peripherals are a little bit more consistent. All the software packages from EAI are still under development. They're a new company in the field and they just haven't had the time to develop software that CDC and SDS have. In the CDC 3300, we have Fortran's incompatibility with the 7094. We have no time sharing software available at the time of delivery. We have no hybrid applications support software. In the 9300 we have, relative to the others, relatively poor access to the digital peripheral equipment. We have no relocation hardware. That one core that both of the CPU's can get at, we will have to take extra pains in programming. It's a non-standard configuration and that requires special engineering and problems may crop up of which we are not yet aware. In the 6400, the major weakness is no application support software. However, this is a mitigating circumstance here. Astrodata, which is bidding the 6400, as part of their hybrid system, has underway a company sponsored program to develop applications support software specifically for the 6400. They actually have two projects underway, one a 15 man year project, and the other one, pointed directly at developing operational routines for this system, an 8 man year effort. They expect to have this all accomplished within the next calendar year.

SELECTION ORDER

HARDWARE	SOFTWARE	OVER-ALL SELECTION
CDC 6400	EAI 8400	EAI 8400 *
EAI 8400*	SDS 9300	CDC 6400
CDC 3300	CDC 6400	SDS 9300
SDS 9300	CDC 3300	CDC 3300

* THIS PLACEMENT OVERLOOKS BASIC 7 DIGIT ACCURACY LIMITATION

Chart 23

When we review all of the characteristics of the digital computer and sum them up and come to an overall selection, we feel that the 6400 has somewhat better hardware than anyone else; 8400 is pretty good. They have a problem, of course, with their basic 7 digit accuracy limitation. In software, EAI seems to be clearly superior. They have put much more time and money into this than anyone else. This is their whole commercial and economic future. They have got to make this system fly or they are in serious trouble. SDS, in conjunction with the Beckman system, have spent large amounts of money in writing hybrid software. The CDC units come in a poor third. Overall selection, we feel must go to EAI. Again we have this one problem with the 7 digit accuracy. We've either got to find a way to program our problem around this, or by means of software or manufacturer's modifications, to overcome this problem. The 6400 is second and the SDS is third with the 3300 system's coming in fourth.

PRICE-DELIVERY COMPARISON OF SYSTEM BIDS

MANUFACTURE	DELIVERY 2 ANALOGS	TOTAL SYSTEM DELIVERY	TOTAL SYSTEM COST
ASTRODATA CI 5000/ CDC 6400	5 MO	11.5 MO	\$3,397
ASTRODATA CI 5000/ CDC 3300	5 MO	9.5 MO	3,738
ASTRODATA CI 5000/ SDS 9300	5 MO	9.5 MO	3,857
BECKMAN 2200/ SDS 9300	7 MO	12 MO	4,105
ELECTRONIC ASSOCIATES 8900 (1)	9 MO	18 MO	5,075
ELECTRONIC ASSOCIATES 8900 (2)	9 MO	16 MO	4,158

PRICES ARE IN THOUSANDS OF DOLLARS

Chart 24

Now we look at the price-delivery comparison of the system bids. Astrodata offers us a system consisting of Comcor Ci 5000 analog computers, an interface manufactured by Astrodata and digital computers by CDC, (the 6400 or the 3300) or the SDS 9300. In each case, they can offer us delivery of two analog computers in five months. The total delivery - $11\frac{1}{2}$ months for the one with the 6400 computer, somewhat shorter for the other two. Price, total system cost - - \$3,397,000.00; \$3,738,000; \$3,857,000.00. For the Beckman SDS system, two analog computers in 7 months, total system in 12, for \$4,105,000.00. For EAI, two analog computers in 9 months, total system delivery in 16-18 months, and the price is \$5,000,000.00 for the system which basically meets all of our requirements and \$4,158,000.00 for their standard system which falls somewhat short of what we think the system should contain. Now we have received telegrams from EAI as late as yesterday afternoon. They offer us one analog computer in $4\frac{1}{2}$ months, and a second analog computer in 7 months. Now they do this by taking analog computers which are earmarked for other customers and diverting them to Lockheed. We are a little puzzled by this because we are not sure that they will get all of the features into these machines that we require. We don't know how far down in the production line these units are. One of the things that we required was additional multipliers in each of the racks so that we could get an adequate number of multipliers in four computers. We suspect that maybe the multipliers on a system like that might come after the basic system was delivered. They can shorten the delivery time on the entire system by 2 to 3 months. They have also offered a modification to the logic in the interface. If they degrade the logic in this system and take out their really high class logic and substitute logic that is adequate for our needs, but of a less expensive nature, they can reduce this price by $\frac{1}{2}$ million dollars. That becomes \$4,500,000.00. This system (No. 2) you will remember had no logic in the interface; if they add the same kind of logic to the interface, it increases this price by \$200,000.00, making it \$4,258,000.00.

The
WINNER

Chart 25

Now after having gone through all the major points, looking at the various systems configurations, the hardware performance, the software, the price, the delivery we have come up with a winner for the system. I won't keep you in suspense.

SELECTED SYSTEM

	DELIVERY
ASTRODATA	
● ANALOG	2 IN 5 MO. ARO
● INTERCOM	
● CDC 6400	TO ASTRODATA IN 6 MO ARO
SYSTEM	TO LOCKHEED IN 11.5 MO. ARO

TOTAL PRICE \$ 3,397,000

Chart 26

The winner is Astrodata. They offer us an analog computer from their subsidiary, Comcor. We can have two of them in 5 months after placing the order; they offer us an intracom of their own manufacturer, that is Astrodata, and the digital computer portion of the system is the Control Data 6400. The 6400 will be available for shipment to Astrodata in 6 months. It will then remain in Astrodata for another 5 to 6 months while it is integrated into the total system. Then the total system consisting of the 6400, the two remaining analog computers, and the interface equipment is to be shipped to Lockheed in $11\frac{1}{2}$ months. At Lockheed, the two previously shipped computers will then be integrated into the overall system. The total price for this is \$3,397,000.

That, gentlemen, concludes the presentation. We will be happy to answer questions. We can go back and review any portion of the charts which you so desire. By the way, the total price is slightly more than the amount we originally thought we could obtain the system for. This amount you will remember was established last September, some 7 or 8 months ago. In that time, our requirements have become somewhat better defined - then there has been the normal escalation of prices. However, this total is still within 5% of our original target figure.