THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING

Department of Naval Architecture and Marine Engineering

STUDY OF TWIN- AND TRIPLE-SCREW SYSTEMS FOR ICEBREAKERS

Horst Nowacki
Jacob Arbel
Harjit S. Chopra

ORA Project 08121

Preliminary Report for:

U. S. Coast Guard

Administered through: July 1966

OFFICE OF RESEARCH ADMINISTRATION · ANN ARBOR

DISPOSITION FORM

(AR 340-15)

REFERENCE OR OFFICE SYMBOL	SUBJECT
NCEED-PB	Great Lakes De-Icing Study - Meeting with Canadian Department of Transport

TO	FROM	DATE	CMT 1
Files	2LT F. Freestone	10 September 1969 LT FREESTONE/tjp/314	

1. Persons present:

<u>U. S. Army Corps of Engineers:</u>
Mr. Robert McKee, Ass't Chief, Planning Branch, Buffalo District
Mr. Philip McCallister, Chief, Planning Branch, Detroit District
Mr. Carl Argiroff, Chief, Navigation Section, Detroit District
Mr. John Borrowman, Consultant, Detroit District
2Lt. Frank Freestone, Planning Branch, Detroit District

<u>Canadian Department of Transport:</u>
Mr. Gordon Stead, Ass't Deputy Minister of Marine Services (opening remarks)
Mr. Donald M. Ripley, Director, Marine Hydraulics (chaired meeting)
Mr. Ralph H. Smith, Chief, Hydraulics Studies
Capt. George C. Leask, Chief, Marine Traffic Control
Mr. A. D. Latter, Superintendent of Pilots
Mr. John N. Ballinger, Ass't Director of Marine Works
Mr. A. Stockdale, Marine Regulations, Nautical
Mr. John Stewart, Marine Operations Planning

<u>St. Lawrence Seaway Authority:</u>
Mr. A. M. Luce, Director of Operations
Mr. Ronald Quail, Ass't Director of Operations
Mr. Walter Webb, Chief, General Engineering Section

2. Mr. Gordon Stead made opening remarks.

3. Mr. McCallister: Briefed the meeting on the purpose, extent, and assumptions of the subject study. Presented somewhat "pessimistic" view of immediate extension of navigation season. Cited conflict of navigation and power.

Mr. Ripley: The Canadian view is "optomistic", and we are working our way in from the Gulf. This does not include the Seaway - DOT has responsibility for the lower St. Lawrence below Montreal; above Montreal is a Seaway problem and will let the Seaway Authority people speak on their own behalf. Cited Quebec and Montreal as being "opened up", in response to pressure from private industry. The Seaway was designed on the assumption that it would not be a year-round operation. Power operations are a real obstacle. Mr. McCallister mentions icebreaking, what about other methods of de-icing?

Mr. McCallister: We have investigated all means of de-icing, by a search of the world's literature. We have prepared estimates of costs of bubbler systems and dusting operations. We have a research program concerning thermal check valves being conducted under contract by Lake Survey. We have contacted AEC regarding atomic power plants located for favorable discharge of thermal rejections. We think of methods other than icebreaking as being complimentary to icebreaking. What are your icebreaking operations?

Stewart: Gulf of St. Lawrence operations started in 1959. Shipping wanted to come into this area. We now receive about 600 ships per season, of which about 250 are ice strengthened. 30 to 70 ships per season become beset in ice, and some of these ships are ice strengthened. There is little record of ice damage to ships, and since even ice strengthened ships become beset, the case for ice strengthening has not yet been made. Ice in the Gulf is not strong enough to cause damage. Labardor ice is harder than Gulf ice. We have a mathematical simulation model by which we can maximize the use of our icebreakers, and minimize the mean waiting time of ships wanting to enter the Seaway. The use of convoys will depend on the frequency of traffic: high traffic fequency will warrant convoying, low traffic frequency will warrant independent operations. We have the mathematical technique for making this decision. The Quebec-Montreal area ice problem is presently treated as a flood-control problem. Icebreakers are used to open the season 1-2 weeks earlier, we have plans for extending. The demand for an increased season on the lakes is economic justification for research on the problem. We view our icebreaker operations as a pipeline problem, the icebreakers are like pumps used to maximize the flow. Formerly, icebreakers were used only for ice jams, now they give assistance to shipping. We have 2 icebreakers on the lakes at present, and are adding the new GRANDVILLE this year. These are 4,500 SHP medium size icebreakers, and are used to hasten the opening date for Port Author and prevent blocking of the Welland. They are used as buoy tenders the rest of the year. We have no plans for adding to this capability, and are investigating the possibility of moving one out to the Gulf for the winter, to return to the Lakes in the spring.

We are presently studying the total Coast Guard requirements for the Lakes, including icebreaking, search and rescue, aids to navigation, etc. Our study assumes no imminent year-round navigation.

Ripley: Ice surveys and Meteorological input to ice reconnaissance is the central part of our approach to the ice problem.

Stewart: Daily DC-4 flights over the Gulf of St. Lawrence provide ice reports for marine traffic control. Little is being done on the Lakes for ice requirements.

Capt. Leask: The Marine Traffic Control intelligence on ice is sent to the two Marine Traffic Control Centers at Quebec and Montreal. Bulletins and forecasts are put out and made available to ships and operating authorities on shore. Instant communications is the key to traffic control. More and better information is requested by the merchantmen when Montreal gets closed up with ice.

Ripley: How about intellegence on the Upper Lakes?

Capt. Leask: There is no ice intelligence on the upper Lakes. There is no pressure to carry this on into the upper lakes during the winter season.

Stewart: Weather flights out of Toronto are scattered.

McCallister: Described efforts of Ice & Snow Project of Lake Survey, aerial recon, surface exploration (treating ice structure as rock), etc. What is your experience on aids to navigation?

Ballinger: In the St. Lawrence River from below Montreal to the Gulf, floating aids are pulled with the onset of ice. We are putting in ranges in narrow channels, such that ships can move at night. Presently we do not have nightime operations. Even the daytime operations are restricted because the spars are only on one side of the channel. The paint gets scraped off by the ice, and a skipper cannot tell which side of the channel is which. In the Gulf areas, for the last 3 or 4 years, major lights have been available 365 days per year. In the lakes, light stations close every fall. We are in the process of installing new communications stations, which will allow us to use the same light stations for automation. Lights and automatic fog alarms will be controlled from a central operating station; 3 lights controlled from one control station. We will eventually extend the system to the Lakes. We will incorporate the systems on the lakes, fog alarms and lights. We are reassessing fog alarms.

McCallister: Vessel operators do not move under adverse conditions. Cited experience.

Ballinger: We have been looking at transponders for use by ships. These are active shore stations that emit a signal every two minutes and require no adjustment to radar sets on board ships. These are better than reflectors which get "lost" against a background of buildings or trees, etc. The disadvantages of transponders is that one can get interference if the devices are spaced too closely on the shore. They may be useful on range towers, and we are trying this expermentally.

McCallister: Blizzard conditions are real delaying factors; conservative skippers will hug shore in preference to moving into heavy seas. How about electronic aids?

Ripley: We are installing an electronic fixing device in Lake St. Peter. Heavy weather is a real problem - if a day is lost due to poor visibility, the whole river will freeze over (due to lack of traffic).

McKee: Do you (DOT) have trouble keeping icebreakers in operation during bad weather, with thoroughly trained crews?

Ripley: We have generally underrated their capabilities.

Stewart: Two to three years ago we used to stop at night, now we have 100% 24 hour operation below Quebec in the Gulf.

Ripley: A lot depends on the ship operator. Some operate notwithstanding the conditions. Icebreaking in the lower River was pioneered by the industry. We helped by ice jam removal.

McCallister: Were those vessels powerful with good bow configuration?

Capt. Leask: Those ships were built specifically for the trade.

McCallister: Does your Coast Guard have any power requirements?

Stewart: We have recommendations, but do not have regulations which we enforce.

Ripley: Are there any problems with the pilots?

Latter: There is no strong opposition from the pilots to operate 24 hours per day. Every ship carries at least one pilot; most of the ships are foreign.

Leask: The shipowners "police" themselves. They will not charter ships that would not hold up to ice operations.

Latter: Two pilots are required for ice operations between December 6 and April 1. Some of the more able ships need only one pilot; the pilots agree with the owners on how many pilots per ship.

Smith: Discussed conflict of power and navigation in the St. Lawrence at Cornwall. Normally shipping terminates about time the booms should be closed due to the weather. At Beauharnois there is a 30 mile canal, artifically dug, with high current velocities. The requirements of navigation and power have been somewhat conflicting here.

McCallister: If the booms could be closed with a shore based winch, one big enough to close during an ice run, would the problems be mitigated?

Webb: The power plants would probably suffer some losses anyway. Not being able to close the booms is not the whole problem. With ships moving, the ice may still jam, or at least reduce the flow of water to the intakes of the power plant.

Luce: We have investigated separating the power and navigation canals at Beauharnois, by use of cribs with ice booms between. It would be very expensive. We announced last January (1969) that the coming navigation season would be 1 April to 12 December. We can keep open, we think, to 15 December, but are allowing ourselves a little breathing space. We refer to these dates as "firming up" of the season for the benefit of foreign shippers who want to schedule additional trips into the seaway without getting trapped. The Welland could go on into January with no trouble, but Lake Erie would still create problems. Port Colburn problems are due to the inability to flush ice through the low-headed lock #8. Beauharnois is a problem area in the St. Lawrence. By additional efforts we could firm 1 April to 31 December.

Borrowman: Perhaps a thermal plant located upstream of Beauharnois would reduce the ice blockage of the intakes of the run-of-the-river plant and make up any head loss that did occur.

McCallister: There are many factors to the location of a power plant.

Ripley: An incentive (tax) to the location of thermal plants might help. The Canadians are wary of any ice condition that might reduce the flow from Lake Ontario. The level of the lake is critical, and is subject to regulation by the IJC. The flow regulation of water and broken ice in combination is difficult, and navigation would not make it any easier. The ice boom at Beauharnois was installed through agreement with the DOT, however, the agreement did not anticipate winter navigation. There is no economic pressure to bear as to who has the priority - power or navigation. Economics will determine precedence. When time comes to close the booms, the merit of not closing them must be examined.

Luce: The stage of accuracy of forecasting will determine, to a large measure, how firm a "guaranteed" date for opening or closing will be.

McCallister: At the hearing on extension of the season, overseas general cargo shippers made the point repeatedly that with a firm season they could schedule a third trip per year into the Seaway. Presently, they do not present themselves at the Seaway until late April or May. Now that you have announced firm dates for the Seaway, have you noticed any increase in the number of overseas shippers? Does your data show three trips?

Luce: We cannot tell yet. We'll let you know after we analyse the data.

McCallister: Is there any pressure from Canadian shippers to have the season extended? Could we send Canadian shippers a letter similar to the one that we sent to U. S. shippers, inquiring about their ice season plans?

Ripley: There is no pressure that I am aware of. I will advise you by letter about inquiring of Canadian shippers. There have been no formal requests by shipping interests to extend the season, only informal comments and questions.

McCallister: What about a joint icebreaking venture in the event of an extended season?

Stewart: Icebreaking will be put into the total requirement picture of the Coast Guard, and will be utilized to its maximum benefit.

McCallister: The question of the conflict of power and navigation is still unresolved. In our report we cannot propose a solution to the problem at Beauharnois and Cornwall. The problem is an international one, and we cannot make recommendations to Congress without fully conferring with you. Conversly, we cannot slight or ignore the problem.

Ripley: Up to this time, the booms have been installed at the time when navigation normally shuts down due to ice. Ontario Hydro and Hydro Quebec have been quite cooperative with us, and our relations with these organizations are good. Aggrevation of the ice problem in the St. Lawrence will aggrevate the flooding of Lake Ontario. Consider your problem in light of these aspects.

D. Freestone
2LT. Freestone

A USMC L-6 1A

PRINCIPAL DIMENSIONS

Length Overall	620'-0"
Length for Classification	605'-0"
Length on Keel	595'-0"
Beam, Molded	60'-0"
Depth at Side, Molded	35'-0"
Sheer, Forward	7'-7 3/4"
Sheer, Aft	4'-2 1/2"
Camber of Spar Deck	15"
Deadrise	3"
Bilge Radius	3'-9"
Tumblehome	9"
Keel Below Molded Baseline	3/4"

ADMEASUREMENT DATA

Port of Registry	Wilmington, Delaware
Registered Dimensions	604.8' x 60.2' x 30.2'
Builder	American Shipbuilding Co., Cleveland, Ohio
Builder's Hull No.	1009
Year Built	1943
U. S. Maritime Commission Design	L6-S-A1
U. S. Maritime Commission Hull No.	569
Official Number	243612
Gross Tonnage	8758
Net Tonnage	6472

LOADLINE DATA

Top of Deck Line Above Molded Line	1 1/4"
Assigned Freeboard	10'-8 3/8"
Molded Summer Draft	24'-4 1/2"
Midsummer Keel Draft	25'-0 1/2"
Summer Keel Draft	24'-5 1/4"
Intermediate Keel Draft	2[illegible]'-6 1/4"
Winter Keel Draft	22'-4 3/4"

LIGHTSHIP DATA

Ship complete in every respect, with water in boilers at steaming level and liquids in machinery and piping but with all tanks and bunkers empty and no cargo, fuel, fresh water, stores, or crew and effects on board. Lightship weight is 5290 long tons with center 28.88 feet aft of midships based on deadweight survey on March 28, 1970.

B

AAA ?

PRINCIPAL DIMENSIONS

Length Overall	647'-0"
Length for Classification	629'-3"
Length on Keel	620'-0"
Beam, Molded	70'-0"
Depth at Side, Molded	36'-0"
Sheer, Forward	6'-10"
Sheer, Aft	4'-6 1/4"
Camber of Spar Deck	16"
Deadrise	3"
Bilge Radius	3'-9"
Tumblehome	9"
Keel Below Molded Baseline	1 3/8"

ADMEASUREMENT DATA

Port of Registry	Wilmington, Delaware
Registered Dimensions	629.4' x 70.3' x 31.3'
Builder	Great Lakes Engineering Works, River Rouge, Mich.
Builder's Hull No.	299
Year Built	1953
Official Number	265,360
Gross Tonnage	11601
Net Tonnage	8601

LOADLINE DATA

Top of Deck Line Above Molded Line	1 3/8"
Assigned Freeboard	10'-8 1/2"
Molded Summer Draft	25'-4 7/8"
Midsummer Keel Draft	26'-1 3/4"
Summer Keel Draft	25'-6 1/4"
Intermediate Keel Draft	24'-6 3/4"
Winter Keel Draft	23'-4 3/4"

LIGHTSHIP DATA

Ship complete in every respect, with water in boilers at steaming level and liquids in machinery and piping but with all tanks and bunkers empty and no cargo, fuel, fresh water, stores, or crew and effects on board. Lightship weight is 6210 long tons with center 31.44 feet aft of midships based on deadweight survey of June 16, 1970.

HULL SIZE "C"

ICE STUDY

S/S EDWARD L. RYERSON

Table 1

Principal Characteristics

Length Overall	730'-0"
Length Between Perpendiculars	712'-0"
Length on Keel	702'-0"
Beam, Molded	75'-0"
Depth at Side, Molded	39'-0"
Camber	18"
Deadrise	0"
Bilge Radius	3'-9"
Maximum Draft, Summer, Great Lakes	26'-6 1/8"
Displacement, Total, Long Tons	34,135
Light Ship Weight, Long Tons	8,080
Deadweight, Total, Long Tons	26,055
Shaft Horsepower, Normal	9,000
Revolutions per minute at normal power	105
Propeller Diameter	20'-0"
Number of Blades	5
U. S. Gross Tonnage	12,170
U. S. Net Tonnage	7,637
Crew	37

Table 2

Hull Form Data

Displacement Length, (L. B. P.)	712'-0"
Beam, Molded	75'-0"
Design Draft, Molded	26'-6"
Displacement, Molded, Fresh Water, Long Tons	34,080
Length - Beam Ratio	9.49
Beam - Draft Ratio	2.83
Length of Entrance, Feet	142.4
Length of Parallel Middlebody, Feet	391.6
Length of Run, Feet	178.0
Run - Entrance Ratio	1.25
Block Coefficient	0.864
Prismatic Coefficient	0.868
Midship Coefficient	0.997
Water Plane Coefficent	0.895
Vertical Prismatic Coefficient	0.962
Displacement - Length Ratio	94
Longitudinal Center of Buoyancy, Feet Forward Midships	12.9
Wetted Surface, Square Feet	81,184
Designed Sea Speed, Miles per Hour	16.75
Designed Sea Speed, Knots	14.55
Speed - Length Ratio	0.545

Principal Dimensions

Since the vessel principally was to be engaged in the transportation of iron ore from the head of Lake Superior to Indiana Harbor, the maximum overall length and breadth were determined to be 730' and 75' respectively, due to the limitation imposed in transiting the lock at Sault St. Marie. Extensive physical and economic investigations were made to determine the optimum design draft and, again, these were based on the specific trade route noted above. Average operating drafts were obtained by comparing the actual op-

BY J.P.F. | SUBJECT ~~VESSEL STUDY~~ SEA TIME STUDY | JOB NO. 1025-1
DATE 3-12-62 | ~~(... & ...)~~ | SHEET NO. 2-A
CHKD BY | | REF. PLAN

ITEM	MILES TYPE	#1 UP	#1 DOWN	#2 UP	#2 DOWN	#3 UP	#3 DOWN	#4 UP	#4 DOWN
TOLEDO DOCK & WINDING	— RSTD	0.24	0.16	—	0.13	—	0.16	0.30	0.20
TOLEDO DOCK – TOLEDO LT.	7 RSTD	0.79 (8.80)	1.42 (4.90)	0.89 (7.80)		1.02 (6.86)	1.34 (5.22)	1.00 (7.00)	1.50 (4.67)
TOLEDO DOCK - BAR PT	33 RSTD				2.79 (11.82)				
TOLEDO LT. - DET. RIV. LT.	23 RSTD	1.48 (15.54)	1.78 (12.92)			1.47 (15.64)	1.72 (13.37)	1.48 (15.50)	1.84 (12.50)
BAR PT - DET. AMB. BR.	30 RSTD			2.18 (13.77)	2.23 (13.45)				
DET. RIV. LT. - DET. WOOD.	25 RSTD	2.24 (11.16)	2.01 (12.43)			2.10 (11.90)	1.91 (13.09)	2.27 (11.00)	2.08 (12.00)
DET. AMB. BR - HURON LT.	68 RSTD			5.91 (11.50)	5.55 (12.25)				
DET. WOOD. - HURON LT.	66 RSTD	5.74 (11.50)	5.45 (12.11)			5.75 (11.48)	5.37 (12.30)	5.86 (11.25)	5.50 (12.00)
HURON LT - DETOUR	220 OPEN	12.32 (17.82)	13.22 (16.61)	12.59 (17.48)	13.89 (15.84)	12.81 (17.17)	13.72 (16.03	VARIES	
DETOUR - LOCK	45 RSTD	5.04 (8.90)	4.81 (9.37)	4.38 (10.27)	4.32 (10.41)	4.44 (10.14)	4.42 (10.18)	5.17 (8.70)	5.00 (9.00)
LOCK TIME	— RSTD	0.24	0.18	0.99	1.32	0.30	0.20	0.35	0.30
LOCK - GROS CAP	16 RSTD	1.30 (12.20)	2.85 (5.62)	1.14 (14.03)	1.54 (10.30)	1.22 (13.10)	2.08 (7.70)	1.33 (12.00)	2.91 (5.50)
LOCK - WHITEFISH PT	42 BOTH	2.84 (14.70)				2.78 (15.11)	3.71 (11.32)		
GROS CAP - S.B. BKW.	336 OPEN		20.68 (16.20)		21.50 (15.60)				VARIES
WHITEFISH PT - DEVILS IS	285 OPEN	16.80 (16.90)				17.15 (16.62)			
GROS CAP - DEVILS. IS.	311 OPEN			18.21 (17.08)				VARIES	
WHITEFISH PT - S.B. BKW	310 OPEN						19.48 (15.91)		
DEVILS IS S.B. BKW	25 OPEN	1.60 (15.60)		2.11 (11.90)		2.18 (11.47)		VARIES	
S.B. BKW - S.B. DOCK	— RSTD	0.65	0.17	0.62	0.15	0.58	0.21	0.70	0.25
S.B. DOCK & WINDING	— RSTD					0.68			
AV. DELAY TIME AT SEA	— RSTD	0.81 HRS		1.25		1.75		1.60	
SUBTOTAL - RESTRICTED	364	37.36 HRS		35.39 HRS		36.72 HRS		39.04 HRS	
SUBTOTAL - OPEN	1112	66.16 HRS		68.30		68.53 HRS		VARIES	
TOTAL SEA TIME/TRIP	1476	103.52 HRS		103.69 HRS		105.25 HRS		VARIES	

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

Address reply to:
COMMANDER (o-1)
Ninth Coast Guard District
1240 East 9th St.
Cleveland, Ohio 44199

3110
29 August 1969
Serial: 609

From: Commander, Ninth Coast Guard District
To: District Engineer, U. S. Army, Detroit District Corps of Engineers, P. O. Box 1027, Detroit, Michigan 48231

Subj: Great Lakes De-Icing Study

Ref: (a) Your ltr NCEED-PB of 14 July 1969

1. Reference (a) requested a report from the Coast Guard regarding vessel classifications for ice operation, icebreaking assistance requirements, and aids to navigation requirements for extended-season operations by the Great Lakes merchant fleet.

2. The "Report of the Technical Subgroup of the St. Lawrence Seaway Task Force" which has been made available to you by the Commandant, U. S. Coast Guard should provide considerable background data for your study. In addition, I have enclosed Annex W to the Ninth CG District Operations Plan concerning Domestic Icebreaking, Reports, Icebreaking Policy and Icebreaking Doctrine. This annex sets forth operating procedures for the Coast Guard vessels concerned with icebreaking.

3. The following comments pertain to the questions posed in paragraph four of reference (a).

a. Merchant vessels with blunt bows and low horsepower (1800-3000hp) have limited icebreaking capabilities. These vessels have difficulty following in the tracks opened by the icebreaker. Brash ice builds up in front of the blunt bow and causes the vessel to slow and stop.

b. Merchant vessel with an "ice-working" bow configuration and of three to nine thousand horsepower would be of substantial benefit when working in ice. When considering their ice-breaking capabilities only it is estimated that these vessels could continue operations through to 1 February. However, the majority of the U. S. fleet of lake vessels do not have an "ice-working" bow and normally terminate seasonal operations about the first week in December. Factors other than ice are considerations when terminating the shipping season. Some of these factors are (1) storms on the open lake together with freezing temperatures which produce ice topside and adversely affect the stability of the vessel (2) profit versus the escalated insurance rates incident to late season shipping; poor visibility and a reduction of the number of aids to navigation restricting the vessels' operations to daylight hours when in pilot waters also reduces profits (3) lake vessels operating in sub-freezing temperatures not adequately insulated or heated to provide for crew comfort contributing to crew fatigue.

c. Lack of maneuverability by a single screw 730 foot long vessel could preclude independent ice operations. The experiment with the SS MANHATTAN presently operating in the Arctic regions should provide practical answers to this question.

d. It is doubtful whether a bow thruster would improve vessel maneuverability in ice. Vector forces of the ice pack under wind or current pressure conditions would far exceed the vector produced by a bow thruster installation of a vessel beset in ice.

e. It is probable that a bow thruster could be designed that would be invulnerable to ice damage. However, it is questionable whether a bow thruster would be of any advantage in ice which extends below the athwartship tunnel of the thruster as the ice dispersion would be a problem.

4. I concur with your concept of independent operation of merchant vessels assisted by a single or a multi-unit task force of Coast Guard vessels capable of breaking ice and strategically located in areas of known difficult ice barriers. During periods of unfavorable visibility, ice, or storm conditions when several merchant vessels collect in a sheltered area there are some advantages in the task force commander resorting to the convoy system. This is discussed in enclosure one. Due to the depths and currents of the water as well as the wind loading effects and areal extent of the ice in the Straits of Mackinac and Whitefish Bay areas the feasibility of using a bubbler and/or dusting system in these areas is highly questionable. It should be noted that the highly discolored ice in eastern Lake Erie caused by industrial aerial deposits and bottom contact is usually the last ice to disappear in the lakes. Ice in this area is wind rafted and reaches depths of 25 to 50 feet. Ice in this condition has little tendency to melt by thermal radiation. Ice breakers operating in this type of ice conditions are unable to establish tracks in the ice field and must resort to single ship convoy.

5. When considering the extension of the navigational season there are two periods to which we refer; one is the extension of the closure date, the other is advancing the opening date. Providing the considerations mentioned in paragraphs 3b are overcome, it is less difficult to extend the closure date before the heavy ice has been formed and rafted by the late winter storms than it is to advance the opening date. As the Seaway has brought salt water traffic into the lakes we should briefly consider the extension of the season for traffic on the four Great Lakes west of the Welland Canal as opposed to the extension of the season to include the Seaway traffic which is controlled by the Canadian Government and the St. Lawrence Seaway Authority and Development Corporation. The latter is outside the purview of the U. S. Coast Guard but does affect the consideration for providing additional heavy duty icebreakers at a period of time when they could be used to some advantage. As ice is not the major governing factor in extending the closure of the shipping season, the additional icebreaker could best be used to advance the date of the opening of the season. The date which a polar icebreaker could be brought into the Great Lakes is determined by the removal of ice booms and the

opening of the locks of the St. Lawrence River and Welland Canal. One consideration then is whether to permanently station a polar icebreaker within the Great Lakes. As these vessels are single purpose units primarily used for ice breaking it would be considered uneconomical to station a 50 million dollar vessel to break ice for an estimated 30 days a year or 8 per cent of her usable time. It therefore appears that our present practice of bringing a Wind-class breaker in to help open up the season is the more logical plan.

6. With the advent of the 1000 foot long lake vessel with a beam of 105 feet it is obvious that the MACKINAW with a beam of 75 feet will need some assistance if these superlakers are to operate in ice. It would appear then that there will be an operational requirement for an additional multi-purpose vessel in the Ninth CG District. This vessel should have a greater icebreaking capability than the 180 foot buoy tender but something less than the MACKINAW with 10,000 hp. It is conceived that the MACKINAW and this medium class ice breaker working together as a multi-unit task force could satisfactorily extend the shipping season to 1 February and accommodate the super-lakers.

7. If we are to consider a 12 month operation in the Great Lakes then one or more additional polar icebreakers would be required for this difficult task. This would require one of the following actions:

a. Reassessment of priorities for our present fleet of polar icebreakers to provide for one or more heavy duty icebreakers to operate in the Great Lakes from about mid-December to mid-April.

b. Construction of an additional heavy duty icebreaker for assignment to duty in the Great Lakes.

8. Tab A of the "Report of the Technical Subgroup of the St. Lawrence Seaway Task Force" contains a breakdown of capital and annual cost for icebreaking facilities by areas and periods of time. I have no reasons to doubt the validity of the figures presented therein. The Report also treats the requirements for aids to navigation for an extended season. No attempt will be made here to expound on the subject.

9. I trust the above information will meet your needs.

W. F. Rea 3d

W. F. REA III

Encl: (1) Annex W, CCGD9 OPLAN

THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING

Department of Naval Architecture and Marine Engineering

STUDY OF TWIN- AND TRIPLE-SCREW SYSTEMS FOR ICEBREAKERS

Horst Nowacki
Jacob Arbel
Harjit S. Chopra

ORA Project 08121

Preliminary Report for:

U.S. Coast Guard

Administered through:
Office of Research Administration

July 1966
Ann Arbor

I. Objective and Scope.

A parametric study of twin- and triple-screw propulsion systems for large icebreakers is conducted with respect to technical properties and feasibility limits. The study is devoted to the following aspects in particular:

1. Bollard thrust, ahead, conventional propeller
2. Bollard thrust, astern, conventional propeller
3. Bollard thrust, ahead and astern, special compromise propeller, designed for astern operation
4. Propulsive efficiency at advance speed of 1 knot
5. Propulsive efficiency, free running at 18 knots
6. Radial and axial clearances between propellers and hull
7. Steering and maneuverability
8. Propeller excited hull and shaft vibrations
9. Propeller strength
10. Cavitation

    Further, the effect of the following parameters had to be considered:

11. Blade number, three versus four blades
12. Hub size, solid and detachable blade screws
13. Propeller diameter
14. Area and power splitting ratio, 1:1:1 versus 1:2:1
15. Powering (SHP)

The investigation is performed for three ship designs of different size:

Case I:

300' LWL, 28' Draft, 70' Beam, 8,500 Tons

15,000 to 45,000 SHP

Case II:

350' LWL, 30' Draft, 80' Beam, 12,000 Tons

30,000 to 60,000 SHP

Case III:

400' LWL, 30' Draft, 90' Beam, 15,400 Tons

30,000 to 60,000 SHP

At the time of this preliminary report questions 1 through 5, and 10, including the influences listed as 11 through 15, have been analyzed. The evaluations are almost terminated except for some broadening in scope planned for the final report. For the remaining questions the methods of analysis were developed, but no numerical results are available as yet.

II. The Available Disk Area.

The space which can be used for arranging propellers in the stern domain is limited by the dimensions of the ship, i.e. principally by draft and beam, and by the clearances required between hull and propeller. It is usually the aim of any design of heavily loaded propellers such as those for icebreakers to provide as much disk area as possible; the disk area is of foremost importance for the performance of such screws. It is therefore necessary to find the maximum feasible diameters and disk areas of the twin- and triple-screw systems under consideration.

A. The minimum tip submergence for the blade in its top position was specified in the contract as 8 feet minimum.

B. The maximum tip submergence is also given in the contract which states that a margin of one foot below base line must not be exceeded.

C. The lateral extension of the propulsion system is limited by the available beam in general, and in particular by the fact that the propeller shafting has to be of acceptable length and angularity. Also, engines and gears must be conveniently locatable inside the hull. These facts restrict the distance of the shaft axis from the centerplane.

The situation was studied by comparison with similar icebreakers designs. Figures *1*, 2 and 3 show existing or proposed twin-screw

*Note that all figures are given in Appendix II.

designs for which propeller arrangement plans could be found or deduced. Table 1* summarizes how much space is occupied by each of the two propellers, and what percentage of the beam remains free. Less information was available for the triple-screw system. The U.S.S.R. icebreaker "Moskva", the only pertinent evidence on hand, Figure 4, could be evaluated with the help of some reconstructive assumptions.

The majority of the following evaluations were based on propeller diameter/beam ratios 0.232 for each twin propeller and 0.58 for the sum of all triple-screw diameters. The former value corresponds to about the average of the considered twin-screw designs, the latter was derived from the "Moskva". Both values were considered as sufficiently typical of modern design practice to result in fair comparisons. But upon Coast Guard request a great part of the analysis was also carried through for ratios of 0.27 and 0.64 for twin- and triple-screw systems, respectively. These assumptions are close to the limits of the design potential, but not unrealistic.

The following maximum diameters were obtained for <u>twin-screw systems</u>:

	$D_{P_{MAX}}/B=0.232$	$D_{P_{MAX}}/B=0.27$
Case I: 300'x28'x70' ship	$D_{P_{MAX}}$ = 16.25'	$D_{P_{MAX}}$ = 18.9'
Case II: 350'x30'x80' ship	$D_{P_{MAX}}$ = 18.56'	$D_{P_{MAX}}$ = 21.6'
Case III: 400'x30'x90' ship	$D_{P_{MAX}}$ = 20.88'	$D_{P_{MAX}}$ = 23.0'

For <u>triple-screw systems</u>, the useful beam percentage b for all three screws is as follows:

	b/B = 0.58	b/B = 0.64
Case I: 300'x28'x70' ship	b = 40.5'	b = 44.8'
Case II: 350'x30'x80' ship	b = 46.4'	b = 51.2'
Case III: 400x30'x90' ship	b = 52.2'	b = 57.6'

*Note that all tables are given in Appendix I.

The propeller size limitation in the draftwise direction is 21' in Case I, and 23' in cases II and III. So, it is less critical than the beam-wise limitation except in Case III for $D_{P_{MAX}}/B = 0.27$, and for the center screw, when $b/B = 0.64$.

In the triple-screw case the available space b must be distributed among the three propellers. It is assumed that the sum of the propeller diameters equals b so that there is no gap between the disks as seen from behind nor any overlap. This is a recommendable arrangement using the maximum possible space without unfavorable interference between propeller races. A check showed that only small gains could be obtained by permitting some overlap so that it is hardly worthwhile risking detrimental interference effects. The maximum feasible diamters, the areas per screw, and the total disk area of the systems 1:1, 1:1:1, and 1:2:1 are shown in Table 2 for both sets of diameter limitations Note that for the center screw Case III, b/B = 0.64, only 23' diameter could be used because of draft restrictions.

If the beam limitations are 0.232 and 0.58, the split 1:2:1 is most advantageous for all ship sizes. The disk area gains are only small though. The split 1:1:1 results in the second highest disk areas.

If the design is pushed to the limiting ratios of 0.27 and 0.64, the 1:1 split is best in disk area for Cases I and II, but suffers from draft limitations in Case III. Only the split 1:1:1 is not restricted in draft so that its disk area is highest in this case while the 1:2:1 area ratio is second best in every case.

The results show that small variations in ship size and beam and draft limitations may turn one alternative from worse to best although the gains are not dramatic. For optimal solutions careful comparisons are necessary.

III. Bollard Thrust Ahead.

The thrust at zero speed of advance in the ahead direction is evaluated for 3 , and 4 bladed Troost series propellers of two different blade area ratios (B3.50; B3.65; B4.55; B4.70). The thrust is found, first, for various diameters of individual screws. As a function of power input (SHP), and later on for certain twin- and triple-screw combinations.

The calculations are limited to propellers that operate at 120 RPM in the bollard condition. For any diameter and SHP there is an RPM that will give the maximum thrust, and this RPM is in some cases larger than 120 RPM and in some cases smaller than 120 RPM. The investigation covers the commonly used pitch range of P/D = 0.5 to 1.4. The greatest thrusts are obtained at the lowest pitch ratios when SHP and RPM are kept the same. This reflects the gains due to increases in propeller diameter. Lower pitch ratios than P/D = 0.5, or still larger screws, are not recommendable, however, because of the unfavorable performance of such screws at other advance speeds.

The evaluations are based on Troost propeller charts, as published in Reference 10. The B4.70 samples are reproduced here as Figures 5 and 6. These charts have been selected because they permit convenient readings at zero advance number. The Lewis Charts, Reference 12, which are similar, were not available immediately for all parameters of interest.

A sample calculation is given in Table 3. A computer program was written for these calculations. A number of readings was taken from the charts, and the final results were obtained by having the computer interpolate between these readings (Michigan Library Subroutine TAB). The computer output is summarized in Tables 4 through 15.

Figures 7 through 10 illustrate the results. Thrust is plotted against SHP with diameter as the parameter. The domain covers the range of common pitch ratios from P/D = 0.5 to 1.4. Boundary lines for these constant values are given to define the range of practicable propellers.

The bollard condition is normally considered as the governing design condition for icebreaker propeller systems, or else some very low advance speed (see Reference 3). In both events one would tend to select the largest screws with a reasonable pitch ratio so that the maximum possible thrust is obtained. This would lead to pitch ratios near 0.5 if compatible with other performance conditions.

IV. Cavitation.

In order to establish in which range the thrust predictions for Troost propellers can be realized in practice the occurrence of cavitation was checked early in this study.

One cavitation check was based on a curve directly applicable to Troost propellers, Figure 11 of this report, from Reference 11. On this basis, the required blade area ratio for cavitation free operation at 120 RPM and zero speed of advance was computed and plotted against thrust in Figure 12. By comparing this diagram with the curves thrust versus SHP in Figures 7 through 10, it can be concluded that practically all propellers of types B3.50 and B4.55 are subject to cavitation. It takes about 65% to 70% blade area ratio to render, at least at lower SHP, the larger screws free of cavitation.

Since the Wageningen series propellers are not particularly suited for heavy load conditions, and have not been developed for bollard operation either, a check under the previous assumptions is conservative and does not reflect the potential improvements by special propeller designs.

To illustrate the ~~margin~~ scope of possible gains Burrill's cavitation line for heavily loaded propellers has been used for a second check, Figures 11 and 13. While the B3.50 and B4.55 propellers still appear to be insufficient the higher area ratio propellers show considerable improvement and promise satisfactory operation up to 20,000 SHP (B3.65) and 22,000 SHP (B4.70) per screw at diamters around 23' (Figures 7 through 10).

V. Comparison of Bollard Thrust Ahead for Various Arrangments.

The ahead bollard thrust is compared for three different arrangements: Twin propeller (power and area split 1:1), triple (1:1:1), and triple (1:2:1). The maximum feasible diameters for all arrangements were given in Table 2. It was attempted to make comparisons for all of the listed diameters, and also for diameters which were 15% and 30% less than maximum. But in numerous cases, mainly with smaller diameters, no acceptable pitch ratios were reached at the specified bollard RPM.

Three comparisons were made:

Comparison A:

Highest obtainable bollard thrust ahead without cavitation for each arrangement regardless of how much SHP is absorbed. The SHP will therefore differ for the design alternatives. This comparison demonstrates the bollard thrust potential. The Burrill cavitation line is used for this purpose. The evaluations are limited to B3.65 and B4.70 propellers because the lower blade area ratios are subject to cavitation. Only the largest screws in each configuration are considered since they set the limits.

Comparison B:

Bollard thrust ahead versus SHP for all arrangements regardless of cavitation. Parameters in this comparison were: Propeller type (B3.50; B3.65; B4.55; B4.70), ship size, and diameter as above. This comparison shows the thrust obtained at the expense of equal power.

Comparison C:

Highest obtainable bollard thrust ahead at the limiting SHP where the most cavitation-prone arrangement starts cavitating. This comparison is limited to blade area ratios of B3.65 and B4.70. The results were obtained by means of Tables 16 and 17 finding the highest SHP for which all arrangements do not cavitate, using the Burrill cavitation limit.

The comparisons were completed for the two variations in lateral size restriction of the propulsion systems. All results are submitted, but the following comments are limited to the more restricted case; the other results are under review.

The results of comparison A are given in Tables 16 and 17 and Figures 14 through 17. The differences among the various arrangements are small. The trend favors higher disk areas, and is thus advantageous for most 1:2:1 splits. Some of the twin-screw cases are also successful.

No conclusions should be drawn from the fact that the four-bladed propeller is slightly better than the three-bladed one. This is more likely a coincidental property of the two Troost series. Similarly minor deviations in series peculiarities would also explain some seemingly unsystematic trends in the results.

For comparison B the results are presented in Tables 18 through 41, and Figures ~~18~~ 14 through 41. The evaluation covers only those parameter variations with pitch ratios between 0.5 and 1.4.

The three systems are confirmed to be almost equivalent. At greater blade area ratios, and in particular for the greatest design area, Case III, the 1:2:1 split is only slightly superior to the 1:1:1 split.

These gains, wherever they exist, remain hardly noticeable at the limit of cavitation, comparison C; this case is indicated by the arrows in Figures 19 through 41.

The cases of highest total system SHP that can be absorbed without cavitation are summarized in Table ~~47~~ 42. It is mostly that the 1:1:1 split cavitates first.

The data of Table 42 can be used for first orientation as to the highest SHP that be reached for each ship size. It can be expected in general, that the power of the 1:1 and 1:2:1 splitting ratio designs can be increased a few percent.

VI. The Astern Thrust of Troost Propellers at Zero Speed of Advance.

It is a well known fact that a conventional propeller is less effective in generating thrust from a given power input when rotating in the astern direction. Most normal profiles used in propeller design are asymmetrical with respect to nose and tail which results in a less favorable lift versus angle of attack characteristic when the inflow is from the tail end direction.

The magnitude of this influence can be judged by Figure 27, Reference 4, page 36, where the ratio of thrust coefficient C_T over torque coefficient C_Q is plotted against the camber ratio at 0.7 radius for ahead and astern operation. Figure 42 of this report shows an average curve derived from the above diagram and used in this work.

The camber ratio of the Troost propeller series was determined in Table 43 using data from References 6, 10 and 11.

The operating conditions are compared assuming the same power input ahead and astern. It is further assumed for simplification that the full load RPM are equal. In this case,

$$\frac{T_{ASTERN}}{T_{AHEAD}} = \frac{\dfrac{T_{ASTERN}}{p_o^2 \cdot d^2 n^2}}{\dfrac{T_{AHEAD}}{p_o^2 \cdot d^2 \cdot n^2}} = \frac{C_{T\,ASTERN}}{C_{T\,AHEAD}} = \frac{(C_T/C_Q)\ ASTERN}{(C_T/C_Q)\ AHEAD}$$

Where: n = rps
p_o = nose-tail-pitch, ft.
d = propeller diameter, ft.

The quantities involved in the last expression can be read off directly from Figure 42. The results are given in Table 43. The astern bollard thrust of the Wageningen propellers under consideration can be expected to be about 80% of the ahead thrust.

The astern thrusts are plotted against SHP in Figures 43 through 46. The picture of the relative merits of the systems is of course the same as for the ahead condition, as illustrated by Tables 44 through 55, and Figures 47 through 58.

VII. The Ahead and Astern Bollard Thrust of a Compromise Screw.

In the operation of icebreakers the manner of backing out of and down from the ice should frequently require more thrust than that of moving up since no accumulated momentum is there to assist.

In view of this, the Coast Guard contract calls for an evaluation of special propeller designs to operate in the astern direction.

As pointed out in the previous section the inferiority of the backing performance is caused by foil asymmetry. If one wanted to carry the improvement of astern performance to the extreme it would be obviously possible to mount the screws in the opposite sense, with the foil suction sides (backs) away from the ship, and the pressure sides (faces) towards the ship. Although this procedure is not seriously suggested here, it shows to what extent the backing thrust can be improved and at what expense in forward thrust. The magnitude of the potential improvements can be estimated by reading the figures and tables previously given for ahead and astern thrust in the reverse sense.

However, the actual aim is an improvement in astern performance without overdue sacrifices in forward thrust, i.e. a compromise design.

There are mainly two possibilities of directing a design towards more balance between ahead and astern performance:

A. Reduction of profile camber throughout the blade using angle of attack for lift generation instead.

B. Selection of nearly symmetrical foils with respect to the .5 chord-length point (nose half = tail half). This implies symmetrical thickness distributions as well as symmetrical mean lines, such as the C-series mean lines developed by DTMB.

Reducing the camber does produce a better balance of forward and astern thrust, decreasing the length of the lines in the C_T/C_Q - chart, Figure 27 of Reference 4. For a camberless screw ahead and astern thrust would be identical.

There are, however, many practical drawbacks. When the lift is produced solely by angle of attack the pressure distribution is disadvantageous with pronounced peaks at whatever the front edge is in each sense of rotation. If the pressures on the suction side have to be kept safely above the cavitation level more foil length becomes necessary than with the uniform pressure patterns of cambered foils. Besides, flow separation becomes a more serious problem. This causes inferior propeller performance at conditions not too far away from the design point.

Reduction of camber as a design measure should thus be kept within moderate limits.

If perfectly symmetrical foils would be selected the ahead and astern bollard thrust would become equal. This measure would turn the characteristic curves in Figure 27, Reference 4 into a horizontal position. It may also cause a decline of thrust per SHP for the following reason. In order to avoid excessive pressure loading of the foils at both ends instead of just at the trailing edge, longer foils must be used if the peak pressures are limited by cavitation. This means greater frictional losses and lower thrust.

This disadvantage can usually be kept well within acceptable limits. The symmetrical foil or nearly symmetrical foil can therefore be recommended if improved backing thrust per SHP is desired. The consequence of at least some deterioration of forward thrust is in common to all methods of improving astern operation.

In order to estimate how much thrust can be expected from a compromise propeller, for which $T_{ASTERN} = T_{AHEAD}$, Figure 42 may be considered as a typical case:

$$C_T/C_Q = 6.19,$$

the following ratio was found:

$$\frac{T_{COMPROMISE}}{T_{AHEAD}} = \frac{(C_T/C_Q)\ COMPR.}{(C_T/C_Q)\ AHEAD} = \frac{6.19}{(C_T/C_Q)_{AHEAD}}$$

Propeller	B3.50	B3.65	B4.55	B4.70
$(C_T/C_Q)_{AHEAD}$	6.95	6.78	6.87	6.71
T_{COMPR}/T_{AHEAD}	.891	.913	.901	.923

The table shows that in the average one would obtain about 90% of the thrust otherwise reached in the ahead condition.

With the above ratios, compromise propeller thrusts of individual screws, Figures 59 through 62, and systems, Tables 56 through 67 and Figures 63 through 74, are given in the appendices. The system trends are the same as in earlier cases.

VIII. Hub Size Influence.

The hub diameter ratios of Troost propellers are 0.18 for the B3 series and 0.167 for the B4 series. Icebreaker hubs are larger for strength reasons and in particular when detachable blades are used. The influence of hub size shall be investigated comparatively for solid propellers of 0.21, and detachable blade screws of 0.32 hub-diameter ratio.

It should be mentioned that an equation to account for large hubs was given by Milano, Reference 3:

$$T_{\text{Large hub}} = K_1 \cdot T_{\text{Troost}},$$

where $K_1 = 0.97$ for solid screws ($x_h = 0.21...0.22$),

$K_1 = 0.86$ for detachable blades ($x_h = 0.32...0.35$).

It is felt that these corrections are excessive. The factors K_1 are derived from a DTMB report by Shultz, Reference 5, in which the decrease of the ideal thrust loading coefficient C_{T_i} with increasing hub diameter ratio x_h was discussed. Milano adopted these reductions directly and seems to have overlooked that the absorption of input power (C_{P_i}) decreases, too. If the power input is raised to the previous level (by increasing the pitch or the RPM) a substantial part of the thrust loss is recovered. It should be kept in mind, though, that the large hub propeller needs longer, less efficient profiles to avert cavitation.

A different approach was used in an attempt to estimate the inevitable thrust losses for large hubs. The propeller efficiency is determined at a small advance number $J \ll 1$, $\lambda_i \gtrsim 0$, and it is assumed that the efficiency loss percentage caused by the difference in hub size equals the thrust loss percentage at zero advance speed, the power input (SHP) being the same. The propeller efficiency can be represented as product of ideal efficiency η_i (ideal fluid, momentum theory) and blade efficiency ξ (losses in real fluid).

$$\eta_o = \eta_i \cdot \xi$$

The change in expanded blade area ratio, i.e. in thrust generating area, is for large hubs according to Reference 6, page 125:

$$\frac{\Delta a_E}{a_E} = 1.1 \cdot (x_h - 0.18) \text{ for Troost B3 series,}$$

$$\frac{\Delta a_E}{a_E} = 1.1\ (x\ \_0.167) \text{ for Troost B4 series.}$$

In our analysis,

x_h = 0.21 for solid propeller

x_h = 0.32 for detachable blade propeller

The area losses $\Delta a_E/a_E$ are thus:

	Solid	Detachable
B3	0.033	0.154
B4	0.047	0.167

It must be supposed that about the same blade area ratio is required to keep the large hub propeller free of cavitation. The area lost at the hub must be replaced at other radii. The foils must be lengthened by about the same percentage. The ideal thrust loading coefficient is defined as below and increases with hub size:

$$C_{Ti} = \frac{8\,\Gamma}{\pi \rho (D^2 - d_h^2) V_A^2} \cdot \frac{1}{1 - 2\varepsilon\lambda_i}$$

where ε = mean drag-lift ratio

V_A = advance speed, $V_A \ll 1$.

λ_i = hydrodynamic advance number,

$$\lambda_i = \frac{V_A}{\pi n D} \cdot \frac{1}{\eta_i} \ll 1,$$

hence: $\frac{1}{1-2\varepsilon\lambda_i} \approx 1$

It follows that C_T is proportional to the factor:

$$\left(1 - x^2_{h\,\mathrm{TROOST}}\right) \Big/ \left(1 - x^2_{h\,\mathrm{LARGE\ HUB}}\right)$$

Incidentally, the same correction would hold with close approximation for the power loading coefficient C_{P_i} which is also proportional to $(D^2 - d_h^2)$. Both are thus raised by the factor:

	Solid	Detachable
B3	1.02	1.17
B4	1.05	1.20

From this the following changes in η_i can be estimated from the Kramer chart at $\lambda_i \approx 0$.

	Solid	Detachable
B3	0.998	0.98
B4	0.995	0.98

This demonstrates that under the assumption of equal power input the ideal efficiency of large hub propellers is only little smaller than that of regular hub size screws.

There is however a secondary effect upon blade efficiency caused by lengthening the foils. For the increase in mean lift-drag ratio ε

corresponding to this influence it can be estimated from foil data that ε must be multiplied by:

	Solid	Detachable
B3	1	1.1
B4	1	1.1

The blade efficiency ξ would be reduced according to Figure 75 by the factor:

	Solid	Detachable
B3	1	0.98
B4	1	0.98

The rounded total reduction in propeller efficiency is given by the following factors:

	Solid	Detachable
B3	0.995	0.96
B4	0.995	0.96

The thrust losses of a redesigned large hub screw at zero advance speed are of the same order. Milano's thrust loss percentages are much higher because they were based on overestimated η_i losses while the change of blade efficiency was ignored.

IX. Propulsive Efficiency at Speed of Advance of One Knot.

The propulsive efficiency is defined as: $\eta_P = \eta_o \cdot \eta_H \cdot \eta_r$

η_o = open water efficiency

η_H = hull efficiency

η_r = relative rotative efficiency

The open water efficiency was read from the charts, Tables 5 and 6, and similar ones for other propellers. The readings were taken for $J = V_A / n \cdot D$ with V_A = 1 knot and n = 120 RPM = bollard RPM. The change of n when V_A is increased to 1 knot is negligible as shown in the sample calculation, Tables 68 through 70. The sample illustrates further details of the procedure, too. The relative rotative efficiency is set to unity throughout.

For the hull efficiency of a multiple screw system the following expression is derived:

$$\eta_H = \frac{R \cdot V_S}{(TV_A)_{TOTAL}} = \frac{R \cdot V_S}{\sum_i (T_i \cdot V_{A_i})} = \frac{1}{\sum_i \frac{T_i}{R}(1-w_i)} = \frac{1}{\sum_i \frac{T_i}{T} \frac{(1-w_i)}{(1-t_i)}} \approx \frac{1}{\sum_i \frac{SHP_i}{SHP} \frac{(1-w_i)}{(1-t_i)}}$$

where: R = resistance

V_S = ship speed

V_A = propeller advance speed

w = wake fraction

t = thrust deduction fraction

The last step assumes that power split and thrust split are about equal. In the actual calculations the area splitting ratio has been substituted here.

At an advance speed of 1 knot the following data were estimated from similar cases, Reference 7:

Twin Screw:

$$w = t, \eta_H = 1$$

Triple Screw:

Center screw: $w = 0.04$, $t = 0.03$
Outer screws: $w = t$

The sample, Table 70, shows that the hull efficiency is unity for all practical purposes.

The propeller efficiency equals the open water efficiency at this low speed therefore.

The results are shown in Tables 71 and 72 and Figures 76 through 87. It comes as no surprise that the differences between the systems are small. They conform with the bollard thrust trends as could be expected with that little speed difference.

X. Propulsive Efficiency at Speed of Advance of 18 Knots.

The icebreaker designs are assumed to operate at 18 knots free running speed. The evaluation of their propulsive efficiency is similar to the procedures of the previous section with one main exception; in the low speed case the circumstances of ice operation determine the SHP which could vary in wide limits, whereas the SHP, free running, is a single value depending on the resistance of the design, i.e. its EHP, and its propulsive efficiency, both unknown.

The EHP can only be estimated from series data at this stage. Series 60 (C method), and Taylor's standard series both fail to give acceptable results because the icebreakers differ strongly from the series hull shapes, and their form parameters are not covered satisfactorily by the series.

An attempt to use Ayre's method of EHP estimation, sample presented in Table 73 based on Reference 10, yields results which are not consistent in themselves either with respect to ship size, but are at least in the right range in comparison with similar ships. About 10,000 EHP seem to be needed to go 18 knots. Since all obtainable estimates were not fully satisfactory it was decided to cover a range of SHP so that the curves can be used more specifically as soon as more reliable EHP data are available.

The SHP range was chosen wide enough to include powers higher than those expected as necessary for 18 knots in order to keep the data applicable for higher service speeds if such should be selected later. The following power range was covered:

Ship size Case I: 6,000 to 30,000 SHP

Ship size Case II: 9,000 to 39,000 SHP

Ship size Case III: 6,000 to 36,000 SHP

The comparisons were conducted for the systems pitched for the best bollard thrust because it is common and recommendable practice to design icebreaker propulsion systems for very low or zero design speed. The pitch ratios and propeller diameters chosen for bollard operation and used in the following are summarized in Tables 73 and 74.

The possibility of cavitation was ignored in selecting the best bollard thrust systems as well as in finding the propulsive efficiencies. This was done in the assumption that while the Wageningen series propellers might cavitate in some states the redesigned special icebreaker screws could be kept free of cavitation through most of the investigated SHP range. However, the findings for SHP in the upper domain should be interpreted cautiously.

The relative rotative efficiency was again assumed to be unity although this neglects the slight advantages that triple screw systems should have over twin systems at this speed.

The hull efficiency of the center screw is expected to be more favorable than that of the outer screws of triple or twin systems because of the beneficial influence of the boundary layer energy recovered from the wake by the center screw. This results in a wake fraction exceeding the thrust deduction fraction, thus $\eta_H > 1$. The following data, Table 74, were adopted as estimates for w and t after analyzing some similar designs and available equations. It was felt that these data were typical enough for the purpose of preliminary design comparisons. A thrust deduction fraction of only 0.15 may sound optimistic even though w is estimated relatively low, too, but in our opinion this low level of t, which results in $\eta_H \approx 1.13$, can be reached by successful stern designs.

Although the center screw alone reaches substantial gains in η_H a lot of this is averaged out in ~~twin~~ triple screw systems. The results are $\eta_H = 1.03$ for the 1:1:1 power split, and $\eta_H = 1.046$ for the 1:2:1 split. For derivation see Tables 74 and 75.

The number of revolutions at which the propellers absorb the SHP must be determined by a trial and error procedure outlined in the sample in Tables 76 through 79.

The results are presented in Tables 80 through 88, and Figures 88 through 105. The tendencies differ appreciably in comparison with the bollard condition. In a majority of cases, predominantly so in the lower SHP range of each ship size, the power split 1:1:1 is best, 1:2:1 second best and 1:1 weakest. There are however a few cases at higher SHP where the 1:1 split is best.

The differences in propulsive performance at 18 knots stem from the fact that the pitch ratios were selected for the bollard condition and are not optimal when free running. The twin system and the 1:2:1 split are associated with lower pitch ratios than the 1:1:1 system, and their pitch is less than optimal at 18 knots. The losses in this free running condition under partial load greatly exceed the gains in hull efficiency experienced by the triple systems.

These losses can be reduced somewhat by proper designing:

A. One can try to work with profiles that perform better at negative angles of incidence as associated with the "underpitch" at 18 knots.

B. If a little bollard thrust is sacrificed more pitch can be permitted. This measure can also be termed: Designing for higher speeds somewhere between bollard and free running condition.

It should be noted that the desired free running number of revolutions n = 150 RPM could not be maintained exactly since the design parameters were fixed by other assumptions, but it is well within the range of variation covered here.

XI. Open Questions.

The questions of steering, vibrations, strength, proper clearances are still under consideration, and no numerical work has been terminated so far.

If conclusions are sought on the basis of analytical relations and judgment the following expectations could be given now:

Steering and maneuvering: Definite gains for both triple systems, most noticeably at lower speeds.

Vibrations: Center screws tend to operate in less uniform inflow than outer screws so that there may be a little more shaft vibration excitation. As to hull vibration, the location of a center screw is more likely to coincide with an antinode while the outer screws are closer to nodal positions thus transferring less energy of excitation.

It is not believed, though, that the excitation pressures on the hull as evaluated for the different systems will differ greatly.

Strength: It is still thought possible that the triple systems which have lower SHP per blade are somewhat more favorable.

Clearances: Great axial clearances are recommended from practically every point of view: vibrations, cavitation, performance.

The radial clearances should not be greater than customary. This would result in great disk areas and high thrust; vibrational and other aspects should not be of prime significance.

Propeller submergence: The propeller is generally arranged far enough away from the water surface to avoid air suction, and far enough under the stern overhang to avoid excessive vibrations. The possible changes have little bearing on cavitation. For an ice-breaker, in addition, it seems recommendable to assure that average size icefloe when floating on the water surface does not get too close to the propeller tips to be sucked into the disk. This should reduce the number of ice impacts.

No other special arguments are seen now that would limit the designer in selecting the propeller submergence.

XII. General Conclusions.

None of the systems show major advantages in the bollard conditions. The tendencies go with the available disk area. This makes the 1:2:1 system slightly superior to the others. The astern and compromise performance at zero advance speed, and the efficiency at one knot are in line with the above tendencies.

The 1:1:1 performs best in the free running condition while the other two are underpitched for free running under partial load.

No major drawbacks, but some improvements, e.g. as to steering, are expected for the triple screw systems from the points of view presently under evaluation.

It would thus be recommended, if somewhat better performance and greater reliability justify the added expense, to develop the 1:2:1 or the 1:1:1 triple screw system depending upon how much significance is attributed to good free running efficiency.

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14.

APPENDIX I: TABLES

TABLE 1 DIAMETERS FOR TWIN SCREW SYSTEMS

a. AVERAGE VALUES FROM EXISTING DESIGNS (BASED ON FIGURES 1-3, APP. II)

Fig. No	Propeller dia. / Beam	Space between prop's / Beam	Side Spacing / Beam
1	0.210	0.111	0.234
2	0.241	0.138	0.190
3	0.244	0.082	0.214
Average	0.232	0.110	0.213

b. DIAMETERS (AVERAGE AND LIMIT*)

CASE NO., LENGTH, BEAM, DRAFT. [FT]	AVERAGE DIAMETER [FT]	LIMIT DIAMETER [FT.]
I 300 × 70 × 28	16.25	18.90
II 350 × 80 × 30	18.56	21.60
III 400 × 90 × 30	20.88	23.00**

* LIMIT DIAMETER FROM COAST GUARD SUGGESTION OF (PROP. DIA. / BEAM) = 0.27

** LIMITED BY DRAFT RESTRICTION.

TABLE 2 MAX FEASIBLE DIAMETERS AND AREAS

ARRANGEMENT		CASE	AVERAGE VALUES (*)			LIMIT VALUES (**)		
			DIAMETER FT	AREA SCREW [FT²]	TOTAL AREA [FT²]	DIAMETER [FT]	AREA SCREW [FT²]	TOTAL AREA FT²
TWIN SCREW		I	16.25	207.5	415.0	18.90	280.6	561.2
TWIN SCREW		II	18.56	270.6	541.2	21.60	366.4	732.8
TWIN SCREW		III	20.88	342.5	685.0	23.00	415.5	831.0
TRIPLE SCREW 1:1:1		I	13.50	143.1	429.3	14.93	175.1	525.3
TRIPLE SCREW 1:1:1		II	15.46	187.7	563.1	17.07	228.9	686.7
TRIPLE SCREW 1:1:1		III	17.40	237.8	713.4	19.20	289.5	868.5
TRIPLE SCREW 1:2:1	C.S.	I	16.88	223.9	443.1	18.56	270.4	540.8
TRIPLE SCREW 1:2:1	O.S	I	11.81	109.6		13.12	135.2	
TRIPLE SCREW 1:2:1	C.S	II	19.20	289.5	580.1	21.21	353.4	706.8
TRIPLE SCREW 1:2:1	O.S	II	13.60	145.3		15.00	176.7	
TRIPLE SCREW 1:2:1	C.S	III	21.62	367.0	734.0	23.00	415.5	831.0
TRIPLE SCREW 1:2:1	O.S	III	15.29	183.5		16.27	207.8	

* Found from existing designs :

$D_{MAX}/B = 0.232$; $b/B = 0.58$

** Set by Coast Guard :

$D_{MAX}/B = 0.270$; $b/B = 0.64$.

TABLE 3. SAMPLE CALCULATION

BOLLARD CONDITION THRUST

Let's take $D = 16.0$ ft, $SHP = 10{,}000$,

$M = 120$ RPM $= 2$ RPS, $\rho(59°F) = 1.9905 \frac{lb\ sec^2}{ft^4}$.

$$K_Q = \frac{Q}{\rho n^2 D^5} \quad \text{where} \quad Q = \frac{550 \cdot SHP}{2\pi \cdot n\,[RPS]},$$

$$\text{So } K_Q = \frac{550\ SHP}{2\pi \rho n^3 D^5} = 43.97 \frac{SHP}{n^3 D^5}$$

$$K_Q = 43.97 \frac{10000}{2^3 \cdot 16^5} = 0.0524$$

Entering the Henschke diagram for the above K_Q and $J = 0$ we find:

$P/D = 0.891$

For this P/D and $J = 0$ we find

$K_T = 0.395$

The thrust can be found now by:

$$T = \rho n^2 D^4 K_T = 1.9905 \cdot 2^2 \cdot 16^4 \cdot 0.395 = 20.62 \cdot 10^4$$

$T = 20.62 \cdot 10^4$ lbs

TABLE 4 THRUST vs. SHP AT BOLLARD

DIAMETER = 12.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10^4 lb	P/D	T 10^4 lb	P/D	T 10^4 lb	P/D	T 10^4 lb
2500	.963	6.63	.922	6.39	.943	6.63	.914	6.72
5000	1.430	9.11	1.303	9.43	1.437	9.26	1.253	9.55

DIAMETER = 13.0 FT

SHP	P/D	T	P/D	T	P/D	T	P/D	T
2500	.797	7.40	.737	6.88	.746	7.27	.747	7.35
5000	1.127	10.56	1.051	10.52	1.117	10.83	1.045	10.92
7500	1.434	12.58	1.366	13.02	1.442	13.83	1.256	13.66
10,000	HI	-	1.434	14.17	HI	-	1.444	15.37

DIAMETER = 14.0 FT

SHP	P/D	T	P/D	T	P/D	T	P/D	T
2500	.640	7.79	.613	7.44	.614	7.35	.614	7.69
5000	.927	11.54	.869	11.31	.901	11.62	.819	11.9
7500	1.157	14.45	1.070	14.40	1.133	14.32	1.062	14.83
10,000	1.372	16.28	1.250	16.50	1.367	16.55	1.212	17.47
12500	1.512	18.02	1.371	18.57	1.557	[illegible]	1.328	19.64
15000	HI	/	1.431	19.63	HI		1.475	20.7

TABLE 5 THRUST VS. SHP AT BOLLARD

DIAMETER = 15.0 FT

Propeller Type	B - 3.50		B - 3.65		B - 4.55		B - 4.70	
Shp	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs
2500	.531	8.01	.511	7.71	.502	8.10	.508	8.17
5000	.788	12.97	.728	12.02	.737	12.74	.739	12.85
7500	.955	16.13	.894	15.44	.934	16.17	.900	16.26
10,000	1.112	18.51	1.04[illegible]	18.44	1.103	18.99	1.034	18.95
12,500	1.276	20.44	1.168	20.72	1.260	20.87	1.147	21.45
15,000	1.418	22.05	1.291	22.83	1.422	22.45	1.244	23.52
17,500	HIGH	%	1.387	24.38	HIGH	%	1.322	25.20
20,000	HIGH	%	1.433	25.10	HIGH	%	1.426	27.11

TABLE 6 THRUST VS. SHP AT BOLLARD

DIAMETER = 16.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs
2500	(.487)	(9.22)	(.422)	(7.23)	(.405)	(7.47)	(.428)	9.61
5000	.651	13.57	.620	12.88	.623	13.78	.623	13.37
7500	.821	17.57	.762	16.43	.771	17.22	.770	17.44
10,000	.937	20.48	.880	19.58	.915	20.44	.891	20.62
12500	1.052	22.91	.988	22.59	1.042	23.35	.988	23.29
15,000	1.169	24.96	1.084	24.88	1.156	25.58	1.074	25.64
17,500	1.287	26.60	1.177	27.03	1.272	27.15	1.154	27.99
20,000	1.392	28.09	1.267	29.03	1.390	28.55	1.225	30.23
22,500	1.473	29.72	1.346	30.71	1.495	30.65	1.290	32.22
25,000	Hi	%	1.404	31.90	Hi	%	1.354	33.85
27,500	Hi	%	Hi	%	Hi	%	1.422	35.05

TABLE 7 THRUST VS SHP AT BOLLARD

DIAMETER = 17.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
2500	(.480)	(11.51)	(.348)	(5.80)	(.325)	(5.99)	(0.37)	12.34
5000	.547	13.76	.531	13.41	.523	14.15	.527	13.95
7500	.646	18.75	.652	17.42	.657	18.66	.659	18.36
10,000	.815	22.20	.755	21.73	.765	21.77	.764	22.03
12,500	.903	24.98	.847	23.82	.871	24.83	.855	25.07
15,000	.988	27.58	.926	26.60	.972	27.78	.935	27.54
17,500	1.071	29.63	1.006	29.37	1.062	30.29	1.002	30.20
20,000	1.158	31.58	1.075	31.47	1.146	32.37	1.067	32.41
22,500	1.246	33.24	1.144	33.48	1.230	33.99	1.127	34.00
25,000	1.329	34.60	1.212	35.47	1.318	35.23	1.182	36.50
27,500	1.403	36.05	1.278	37.29	1.404	36.65	1.233	38.57
30,000	Hi	%	1.464	37.60	Hi	%	1.281	40.79
32,500	Hi	%	Hi	%	Hi	%	1.328	42.39
35,000	Hi	%	Hi	%	Hi	%	1.377	43.77
37,500	Hi	%	Hi	%	Hi	%	(1.428)	(44.25)

TABLE 8 THRUST VS. SHP AT BOLLARD

DIAMETER = 18.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
5000	(.496)	(15.15)	(.450)	(13.04)	(.435)	(13.52)	(.452)	(15.67)
7500	.582	18.78	.566	18.37	.562	19.52	.563	18.84
10,000	.697	23.61	.652	21.92	.658	23.48	.651	23.10
12,500	.790	26.96	.729	25.01	.739	26.47	.741	26.72
15,000	.862	29.75	.806	28.16	.818	29.25	.811	29.63
17,500	.926	32.29	.868	30.84	.899	32.22	.878	32.47
20,000	.988	34.70	.927	33.48	.973	34.96	.936	35.02
22,500	1.051	36.68	.987	36.16	1.041	37.38	.987	37.29
25,000	1.116	38.48	1.042	38.32	1.106	39.48	1.036	39.40
27,500	1.182	40.32	1.093	40.20	1.168	41.29	1.083	41.45
30,000	1.247	41.80	1.145	42.13	1.231	42.75	1.125	43.54
32,500	1.310	43.09	1.197	44.01	1.298	43.92	1.170	45.63
35,000	1.369	44.41	1.247	45.80	1.363	45.14	1.209	47.63
37,500	(1.412)	(45.83)	1.294	47.45	(1.426)	(46.66)	1.247	47.51

TABLE 9 THRUST VS. SHP AT BOLLARD

DIAMETER = 19.0

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
S.H.P.	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs
5000	(.480)	(17.98)	Low	✓	Low	✓	Low	✓
7500	.515	1978	(.487)	(18.47)	(.470)	(19.31)	(.455)	(20.2[illegible])
10,000	.588	23.62	.571	23.08	.567	24.53	.568	23.65
12,500	.676	28.25	.638	26.49	.642	28.36	.643	27.71
15,000	.753	31.86	.696	29.37	.706	31.38	.709	31.49
17,500	.816	34.71	.757	32.42	.766	34.02	.766	34.45
20,000	.869	37.27	.813	35.33	.827	36.70	.818	37.16
22,500	.917	39.67	.860	37.86	.889	39.52	.869	39.80
25,000	.966	42.01	.904	40.29	.946	42.19	.916	42.36
27,500	1.013	44.11	.951	42.91	1.000	44.64	.957	44.62
30,000	1.061	45.88	.997	45.38	1.052	46.54	.995	46.71
32,500	1.110	47.58	1.038	47.38	1.101	48.52	1.032	48.71
35,000	1.161	49.36	1.077	49.18	1.148	50.59	1.068	50.66
37,500	1.211	50.95	1.116	50.97	1.195	52.15	1.103	52.60

TABLE 10 THRUST VS SHP AT BOLLARD

DIAMETER = 20 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
S.H.P.	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
7500	(.486)	(22.40)	Low	✓	Low	✓	Low	✓
10,000	.521	24.65	(.496)	(23.31)	(.485)	(24.42)	(.493)	(25.21)
12,500	.577	28.29	.561	27.70	.557	29.40	.558	25.92
15,000	.644	32.66	.615	31.13	.617	33.28	.617	32.23
17,500	.711	36.78	.662	34.03	.664	36.45	.671	36.06
20,000	.766	39.82	.707	36.75	.717	39.16	.720	39.40
22,500	.814	42.49	.754	39.67	.764	41.66	.764	42.17
25000	.856	44.97	.799	42.51	.811	44.15	.804	44.73
27,500	.893	47.25	.837	45.00	.859	46.4	.845	47.34
30,000	.931	49.54	.873	47.34	.906	49.49	.883	49.85
32,500	.968	51.74	.907	49.65	.949	51.95	.918	52.15
35,000	1.005	53.77	.943	52.15	.992	54.32	.956	54.33
37,500	1.042	55.50	.979	54.56	1.032	56.47	.980	56.36

TABLE II THRUST VS. SHP AT BOLLARD

DIAMETER = 21 FT.

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs	P/D	T 10⁴ lbs
10,000	(.489)	(27.51)	Low	%	Low	%	Low	%
12,500	.517	29.66	(.490)	(27.81)	(.479)	(29.10)	(.488)	(30.38)
15,000	.559	32.93	.543	32.22	.537	34.09	.539	33.26
17,500	.609	36.92	.588	35.80	.587	38.16	.587	36.75
20,000	.662	41.13	.628	38.83	.631	41.56	.632	40.44
22,500	.714	44.92	.665	41.54	.672	44.48	.674	44.06
25,000	.758	47.83	.699	44.09	.709	47.08	.713	47.29
27,500	.797	50.42	.737	46.87	.746	49.50	.748	50.01
30,000	.831	52.90	.773	49.62	.783	51.83	.780	52.52
32500	.863	55.19	.807	52.26	.819	54.27	.812	54.97
35,000	.892	57.35	.836	54.61	.857	56.83	.844	57.45
37,500	.922	59.54	.864	56.85	.894	59.37	.874	59.85

TABLE 12 THRUST VS SHP AT BOLLARD

DIAMETER = 22.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
S.H.P.	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
12,500	(.488)	(33.07)	LOW	/	LOW	%	LOW	%
15,000	.509	34.95	(.476)	(32.00)	(.463)	(33.38)	(.475)	(35.92)
17,500	.538	37.74	.520	36.56	.511	38.50	.516	38.37
20,000	.575	41.23	.559	40.37	.554	42.83	.556	41.44
22,500	.616	45.14	.594	43.63	.593	46.54	.593	44.85
25,000	.658	49.17	.625	46.52	.628	49.77	.629	48.38
27,500	.700	53.00	.655	49.14	.661	52.63	.662	51.86
30,000	.737	55.96	.683	51.61	.691	55.21	.694	55.17
32,500	.770	58.59	.711	54.12	.721	57.61	.723	57.99
35,000	.800	61.01	.740	56.77	.750	59.89	.751	60.54
37,500	.828	63.39	.769	59.40	.778	62.12	.777	62.93

TABLE 13 THRUST VS SHP AT BOLLARD

DIAMETER = 23.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
S.H.P.	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
17,500	.500	40.72	Low	%	Low	%	Low	%
20,000	.520	42.99	(.494)	(40.56)	(.494)	(42.48)	(.492)	(43.99)
22,500	.546	45.89	.528	44.67	.521	47.13	.525	46.54
25,000	.575	49.28	.559	48.28	.555	51.20	.556	49.53
27,500	.608	53.00	.587	51.41	.586	54.80	.586	52.77
30,000	.641	56.86	.613	54.26	.615	58.0	.615	56.14
32,500	.676	60.66	.638	56.88	.642	60.90	.643	59.51
35,000	.708	64.10	.661	59.33	.667	63.54	.669	62.81
37,500	.737	66.88	.683	61.68	.691	65.99	.695	65.95

TABLE 14 THRUST VS SHP AT BOLLARD

DIAMETER : = 24.0 FT.

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
S.H.P.	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
20,000	(·491)	47.20	LOW	%	LOW	/	LOW	%
22,500	·505	48.94	LOW	%	LOW	%	LOW	%
25,000	·522	51.23	(·498)	(48.52)	(·487)	(50.85)	(·495)	(52.38)
27,500	·543	54.00	·525	52.47	·517	55.31	·521	54.83
30000	·566	57.17	·550	55.99	·545	59.32	·547	57.62
32,500	·591	60.63	·574	59.17	·571	62.93	·571	60.64
35,000	·618	64.28	·596	62.06	·595	66.22	·595	63.52
37,500	·646	67.98	·617	64.74	·618	69.22	·619	67.06

TABLE 15 THRUST VS SHP AT BOLLARD

DIAMETER = 25.0 FT

Propeller Type	B-3.50		B-3.65		B-4.55		B-4.70	
SHP	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs	P/D	T 10^4 lbs
25,000	(.493)	(55.84)	Low	/	Low	/	Low	/
27,500	.504	57.54	Low	%	Low	/	Low	%
30,000	.518	59.68	(.491)	(56.05)	(.480)	(58.61)	(.459)	(61.11)
32,500	.534	62.21	.514	59.98	.505	63.09	.511	63.39
35,000	.552	65.08	.536	63.55	.529	67.14	.532	65.87
37,500	.572	68.22	.556	66.82	.551	70.86	.552	68.64

TABLE 16 MAX THRUST WITHOUT CAVITATION - AVERAGE DIAMETERS

ARRANGEMENT		CASE	PROPELLER DIA. [FT]	THRUST/SCREW 10^4 LBS.		SHP/SCREW 10^4 HP		TOTAL THRUST 10^4 LBS		TOTAL SHP 10^4 HP		THRUST/SHP LBS/HP	
				B-3.65	B-4.70	B-3.65	B-4.70	B-3.65	B-4.70	B-365	B-470	B-365	B-4.70
TWIN SCREW		I	16.25	18.4	18.5	0.80	0.76	36.8	37.0	1.60	1.52	23.0	24.4
TWIN SCREW		II	18.56	25.5	26.2	1.23	1.20	51.0	52.4	2.45	2.40	20.8	21.8
TWIN SCREW		III	20.88	33.4	34.9	1.63	1.63	66.8	69.8	3.25	3.25	20.35	21.48
TRIPLE SCREW 1:1:1		I	13.50	11.8	12.0	0.53	0.58	35.4	36.0	1.575	1.725	22.5	20.85
TRIPLE SCREW 1:1:1		II	15.46	16.0	16.0	0.78	0.73	48.0	48.0	2.325	2.10	20.6	22.80
TRIPLE SCREW 1:1:1		III	17.40	22.0	23.0	1.06	1.05	66.0	69.0	3.188	3.15	20.7	21.9
TRIPLE SCREW 1:2:1	C.S	I	16.88	19.8	20.4	0.975	0.925	34.5	38.4	1.835	2.025	18.99	17.0
	O.S		11.81	7.5	9.0	0.43	0.55						
TRIPLE SCREW 1:2:1	C.S	II	19.20	27.5	29.0	1.325	1.34	51.3	53.4	2.385	2.492	21.5	21.4
	O.S		13.60	11.9	12.2	0.53	0.577						
TRIPLE SCREW 1:2:1	C.S	III	21.62	35.9	38.0	1.72	1.75	67.7	68.4	3.22	3.15	21.0	21.7
	O.S		15.29	15.9	15.2	0.75	0.70						

T.17 COMPARISON A : MAX. THRUST WITHOUT CAVITATION# (LIMIT DIAMETERS)

ARRANGEMENT		CASE	PROP DIA. [FT]	THRUST / SCREW* 10^4 lbs		SHP / SCREW** 10^4 HP		TOTAL THRUST 10^4 lbs		TOTAL SHP 10^4 HP		THRUST / SHP lbs/HP	
				B-3.65	B-4.70	B-3.65	B-4.70	B-3.65	B-4.70	B-3.65	B-4.70	B-3.65	B-4.70
TWIN - SCREW		I	18.90	26.2	31.8	1.27	1.47	52.4	63.6	2.54	2.94	20.6	21.6
TWIN - SCREW		II	21.60	35.8	38.0	1.73	1.77	71.6	76.0	3.46	3.54	20.7	21.5
TWIN - SCREW		III	23.00	42.0	44.6	2.00	2.08	84.0	89.2	4.00	4.16	21.0	21.4
TRIPLE - SCREW 1:1:1		I	14.93	14.9	14.2	0.71	0.64	44.7	42.6	2.13	1.92	21.0	22.2
TRIPLE - SCREW 1:1:1		II	17.07	20.3	21.8	0.99	0.99	60.9	65.4	2.97	2.97	20.5	22.0
TRIPLE - SCREW 1:1:1		III	19.20	27.3	28.8	1.32	1.32	81.9	86.4	3.96	3.96	20.7	21.8
TRIPLE SCREW 1:2:1	℄	I	18.56	25.0	30.2	1.21	1.29	47.0	53.2	2.23	2.43	21.1	21.9
TRIPLE SCREW 1:2:1	OBD.	I	13.12	11.0	11.5	0.51	0.57						
TRIPLE SCREW 1:2:1	℄	II	21.21	34.3	36.4	1.68	1.69	63.1	65.2	3.12	3.01	20.2	21.7
TRIPLE SCREW 1:2:1	OBD.	II	15.00	14.9	14.4	0.72	0.66						
TRIPLE SCREW 1:2:1	℄	III	23.00	42.0	44.6	2.00	2.08	78.0	81.2	3.78	3.72	20.6	21.8
TRIPLE SCREW 1:2:1	OBD	III	16.27	18.0	18.3	0.89	0.82						

* Max. thrust for corresponding dia., without cavitation

** SHP corresponding to the thrust found in (*)

\# Burrill's heavily loaded propellers cavitation limit used.

TABLE 18 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	17.3	14.0	—	25.2	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	34.6	28.0	—	50.4	—	—	—	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	11.0	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	33.0	—	—	—	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	17.4	14.9	—	27.0	—	—	—	—	—
	SHP/SCREW	3,750			7,500			11,250		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE *19* COMPARISON OF THRUSTS

AHEAD OPERATION *AVERAGE DIAMETERS*

CASE: *I* PROPELLER TYPE: *B-3.65*

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	16.1	14.2	—	25.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	32.2	28.4	—	50.0	—	—	—	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	11.0	8.5	—	15.5	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	33.0	25.5	—	46.5	—	—	—	—	—
TRIPLE SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	16.2	14.8	10.0	26.0	20.5	—	—	—	—
1:2:1	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	8.0	—	—	10.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	32.2	—	—	46.0	40.7	—	—	—	—

TABLE 20 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	17.2	14.2	—	26.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	34.4	28.4	—	52.0	—	—	—	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	11.0	8.0	—	16.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	33.0	24.0	—	48.0	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	17.5	15.0	—	27.0	—	—	36.0	—	—
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs.	7.5	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	32.5	—	—	—	—	—	—	—	—

TABLE 21 — COMPARISON OF THRUSTS

AHEAD OPERATION — AVERAGE DIAMETERS

CASE: I — PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	17.2	14.4	—	26.01	—	—	33.0	—	—
	TOTAL THRUST 10^4 lbs	34.4	28.8	—	52.02	—	—	66.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	11.0	8.0	24.0	16.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	33.0	—	—	48.0	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	18.0	14.8	—	27.6	—	—	33.0	—	—
	SHP/SCREW	3,750			7500			11,250		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 22 COMPARISON OF THRUSTS

AHEAD AVERAGE DIA.

CASE: 11 PROPELLER TYPE: B-350

ARR.	SHP TOTAL	50,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	30.8	24.0	—	38.4	—	—	43.5	—	—
	TOTAL THRUST 10^4 lbs	61.6	48.0	—	76.8	—	—	87.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	19.20	—	—	23.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	57.6	—	—	69.0	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15000			22500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	32.0	25.5	—	40.4	—	—	46.6	—	—
	SHP/SCREW OS	7500			11,250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	13.4	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	58.8	—	—	—	—	—	—	—	—

TABLE 23 — COMPARISON OF THRUSTS

AHEAD — AVERAGE DIA.

CASE: II — PROPELLER TYPE: B-3.65

ARR.		30,000			45,000			60,000		
	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	29.0	24.0	—	37.2	—	—	44	—	—
	TOTAL THRUST 10^4 lbs	58.0	48.0	—	74.4	—	—	88	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	18.8	14.8	—	23.5	—	—	27.0	—	—
	TOTAL THRUST 10^4 lbs	56.4	44.4	—	70.5	—	—	81.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	30.0	25.2	—	38.5	—	—	45.8	—	—
	SHP/SCREW OS	7500			11,250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	14.0	—	—	16.4	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	58.0	—	—	71.3	—	—	—	—	—

TABLE 24 COMPARISON OF THRUSTS

AHEAD AVERAGE DIA.

CASE: II PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,5000			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	30.2	25.0	—	38.4	—	—	45.0	—	—
	TOTAL THRUST 10^4 lbs	60.4	50.0	—	76.8	—	—	90.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	19.5	—	—	23.6	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	58.5	—	—		—	—	10.8	—	—
TRIPLE SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	31.9	26.2	—	40.2	—	—	47.3		
1:2:1	SHP/SCREW	7500			11,250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	14.0	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	59.9	—	—	—	—	—	—	—	—

TABLE 25 COMPARISON OF THRUSTS

AHEAD AVERAGE DIA

CASE: 11 PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	30,000			45000			60,000		
TWIN SCREW	SHP/SCREW	15000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	30.0	25.0	—	38.0	—	—	450	—	—
	TOTAL THRUST 10^4 lbs	60.0	50.0	—	76.0	—	—	90.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	18.0	—	—	24.3	—	—	28.0	—	—
	TOTAL THRUST 10^4 lbs	57.0	—	—	72.4	—	—	84.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	31.0	26.03	—	40.0	32.5	—	47.1	—	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	14.0	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	69.0	—	—	—	—	—	—	—	—

TABLE 26 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	33.4	29.2	—	44.0	36.0	—	52.4	40.5	—
	TOTAL THRUST 10^4 lbs	66.8	58.4	—	88.0	72.0	—	104.8	81.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	22.5	18.0	—	28.5	21.4	—	32.8	—	—
	TOTAL THRUST 10^4 lbs	67.5	54.0	—	85.5	64.2	—	98.4	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,000			30,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	34.2	30.4	22.2	44.6	37.9	—	54.6	43.0	—
	SHP/SCREW	7,500			11,250			15,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	16.7	12.5	—	20.2	—	—	22.8	—	—
	TOTAL THRUST 10^4 lbs	67.6	55.4	—	85.0	—	—	100.2	—	—

TABLE 27 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	31.8	27.8	21.0	41.6	35.5	—	49.0	41.5	—
	TOTAL THRUST 10^4 lbs	63.6	55.6	42.0	83.2	71.0	—	98.0	83.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	21.0	18.0	—	27.0	22.0	—	32.4	—	—
	TOTAL THRUST 10^4 lbs	63.0	54.0	—	81.0	66.0	—	97.2	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	82.8	28.8	22.8	42.7	36.9	—	51.0	43.2	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	15.5	13.0	—	19.9	15.0	—	23.0	—	—
	TOTAL THRUST 10^4 lbs	63.8	54.8	—	82.5	66.9	—	97.0	—	—

TABLE 28 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	34.0	28.8	—	43.8	36.4	—	52.0	41.2	—
	TOTAL THRUST 10^4 lbs	68.0	57.6	—	87.6	72.8	—	104.0	82.4	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	22.0	18.8	—	28.0	—	—	33.0	—	—
	TOTAL THRUST 10^4 lbs	66.0	56.4	—	84.0	—	—	99.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	36.0	30.0	22.5	45.3	38.0	—	53.5	44.0	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	16.8	12.8	—	20.7	—	—	23.4	—	—
	TOTAL THRUST 10^4 lbs	69.6	55.6	—	86.7	—	—	100.3	—	—

TABLE 29 COMPARISON OF THRUSTS

AHEAD OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	33.3	28.9	22.04	43.2	36.4	—	52.0	42.8	—
	TOTAL THRUST 10^4 lbs	66.6	57.8	44.08	86.4	72.8	—	104.0	85.6	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	22.03	18.02	—	28.3	23.0	—	33.2		
	TOTAL THRUST 10^4 lbs	66.09	54.06	—	84.9	69.0	—	99.6		
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	34.8	29.9	23.5	44.5	38.0	—	53.5	44.8	—
	SHP/SCREW	7,500			11,250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	16.0	13.0	—	20.4	—	—	24.0	—	—
	TOTAL THRUST 10^4 lbs	66.8	55.9	—	85.3	—	—	101.5	—	—

TABLE 30 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: I PROPELLER TYPE: B-3.50

AR...	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.90	16.05	13.23	18.90	1605	13.23	18.90	16.05	13.23
	THRUST PER SCREW 10^4 lbs	20.0	17.6	12.8	31.2	25.2	H	39.2	H	H
	TOTAL THRUST 10^4 lbs	40.0	35.2	25.6	62.4	50.4	H	78.4	H	H
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	14.93	12.69	10.45	14.93	12.69	10.45	14.93	12.69	10.45
	THRUST PER SCREW 10^4 lbs	12.4	9.8	H	18.0	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	37.2	29.4	H	54.0	H	H	H	H	H
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.78	12.99	18.56	15.78	12.99	1856	15.78	12.99
	THRUST PER SCREW 10^4 lbs	19.4	16.8	12.0	30.6	24.00	H	38.2	H	H
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.12	11.16	9.18	13.12	11.15	9.18	13.12	11.15	9.18
	THRUST PER SCREW 10^4 lbs	9.2	H	H	12.4	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	37.8	H	H	55.4	H	H	H	H	H

H STANDS FOR TOO HIGH P/D RATIO, OR TOO SMALL DIAMETER

TABLE 31 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: I PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL		15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW		7,500			15,000			22,500		
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	18.90	16.05	13.23	18.90	16.05	13.23	18.90	16.05	13.23
	THRUST PER SCREW 10^4 lbs		18.2	16.0	13.50	29.20	24.8	H	37.6	30.6	H
	TOTAL THRUST 10^4 lbs		36.4	32.0	27.0	58.4	49.6	H	75.2	61.2	H
TRIPLE SCREW 1:1:1	SHP/SCREW		5,000			10,000			15000		
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	14.93	12.69	10.45	14.93	12.69	10.45	14.93	12.69	10.45
	THRUST PER SCREW 10^4 lbs		11.4	10.00	H	18.0	H	H	H	H	H
	TOTAL THRUST 10^4 lbs		34.2	30.00	H	54.0	H	H	H	H	H
TRIPLE SCREW 1:2:1	SHP/SCREW		7,500			15,000			22,500		
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	18.56	15.78	12.99	18.56	15.78	12.99	18.56	15.78	12.99
	THRUST PER SCREW 10^4 lbs		L	15.6	12.8	29.2	23.6	H	41.6	H	H
	SHP/SCREW										
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	13.12	11.15	9.18	13.12	11.15	9.18	13.12	11.15	9.18
	THRUST PER SCREW 10^4 lbs		9.2	H	H	13.4	H	H	H	H	H
	TOTAL THRUST 10^4 lbs		H	H	H	56.0	H	H	H	H	H

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 32 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: I PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.90	16.05	13.23	18.90	16.05	13.23	18.90	16.05	13.23
	THRUST PER SCREW 10^4 lbs	L	17.2	13.2	30.8	25.8	H	39.6	H	H
	TOTAL THRUST 10^4 lbs	—	34.4	26.4	61.6	51.6	H	79.2	H	H
TRIPLE SCREW 1:1:1	SHP/SCREW	5000			10,000			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	14.93	12.69	10.45	14.93	12.69	10.45	14.93	12.66	10.45
	THRUST PER SCREW 10^4 lbs	12.4	10.0	H	18.8	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	37.2	30.0	H	56.4	H	H	H	H	H
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.78	12.99	18.56	15.78	12.99	18.56	15.78	12.99
	THRUST PER SCREW 10^4 lbs	L	16.8	H	30.4	24.4	H	38.4	H	H
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.12	11.15	9.18	13.12	11.15	9.18	13.12	11.15	9.18
	THRUST PER SCREW 10^4 lbs	9.2	H	H	12.8	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	H	H	55.0	H	H	H	H	H

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 33 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: I PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.90	16.05	13.23	18.90	16.05	13.23	18.90	16.05	13.23
	THRUST PER SCREW 10^4 lbs	L	17.2	13.6	30.2	26.0	H	38.8	32.2	H
	TOTAL THRUST 10^4 lbs	—	34.4	27.2	60.4	52.0	—	77.6	64.4	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	FT	14.93	12.69	10.45	14.93	12.69	10.45	14.93	12.69	10.43
	THRUST PER SCREW 10^4 lbs	12.00	10.0	H	18.0	H	H	22.8	H	H
	TOTAL THRUST 10^4 lbs	36.0	30.0	—	54.0	—	—	68.4	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	DIA. %	100	85	70	100	85	70	100	85	70
	FT	18.56	15.78	12.99	18.56	15.78	12.99	18.56	15.78	12.99
	THRUST PER SCREW 10^4 lbs	L	16.4	H	30.0	26.8	H	38.0	H	H
	SHP/SCREW	3,750			7,500			11,250		
	DIA. %	100	85	70	100	85	70	100	85	70
	FT	13.12	11.15	9.18	13.12	11.15	9.18	13.12	11.15	9.18
	THRUST PER SCREW 10^4 lbs	9.6	H	H	13.2	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	—	—	56.4	—	—	—	—	—

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 34 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: II PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	21.60	18.36	15.12	21.60	18.36	15.12	21.60	18.36	15.12
	THRUST PER SCREW 10^4 lbs	34.2	30.4	22.4	44.8	37.2	H	54.4	42.8	H
	TOTAL THRUST 10^4 lbs	68.4	60.8	44.8	89.6	74.4	—	108.8	85.6	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	17.07	14.51	11.95	17.07	14.51	11.95	17.07	14.51	11.95
	THRUST PER SCREW 10^4 lbs	23.0	17.2	H	27.6	H	H	31.6	H	H
	TOTAL THRUST 10^4 lbs	69.0	51.6	—	82.8	—	—	94.8	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	21.21	18.03	14.85	21.21	18.03	14.85	21.21	18.03	14.85
	THRUST PER SCREW 10^4 lbs	34.0	29.9	H	45.6	36.6	H	53.6	41.6	H
	SHP/SCREW	7,500			11,250			15,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	15.00	12.75	10.50	15.00	12.75	10.50	15.00	12.75	10.50
	THRUST PER SCREW 10^4 lbs	16.00	H	H	19.6	H	H	22.0	H	H
	TOTAL THRUST 10^4 lbs	66.0	—	—	84.8	—	—	97.6	—	—

H = P/D HIGHER THAN 1.40

TABLE 35 COMPARISON OF T[illegible]

AHEAD OPERATION LIMIT DIAMETER

CASE: II PROPELLER TYPE: 3.765

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.60	18.36	15.12	21.60	18.36	15.12	21.60	18.36	15.12
	THRUST PER SCREW 10^4 lbs	32.4	28.4	23.0	42.4	36.4	H	50.8	42.8	H
	TOTAL THRUST 10^4 lbs	64.8	56.8	46.0	84.8	72.8	—	101.6	85.6	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.07	14.51	11.95	17.07	14.51	11.95	17.07	14.51	11.95
	THRUST PER SCREW 10^4 lbs	20.4	17.6	H	26.4	21.2	H	31.4	H	H
	TOTAL THRUST 10^4 lbs	61.2	52.8	—	79.2	63.6	—	94.2	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.21	18.03	14.85	21.21	18.03	14.85	21.21	18.03	14.85
	THRUST PER SCREW 10^4 lbs	32	28	21.2	42.4	33.2	H	50.4	42.5	H
	SHP/SCREW	7500			11250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.00	12.75	10.50	15.00	12.75	10.50	15.00	12.75	10.50
	THRUST PER SCREW 10^4 lbs	15.6	12.4	H	19.6	H	H	22.8	H	H
	TOTAL THRUST 10^4 lbs	63.2	52.8	—	81.6	—	—	96.0	—	—

TABLE 36 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: II PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.60	18.36	15.12	21.60	18.36	15.12	21.60	18.36	15.12
	THRUST PER SCREW 10^4 lbs	L	30.0	22.4	45.2	37.6	H	53.6	43.6	H
	TOTAL THRUST 10^4 lbs	—	60.0	44.8	90.4	75.2	H	107.2	87.2	H
TRIPLE SCREW 1:1:1	SHP/SCREW									
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.07	14.51	11.95	17.07	14.51	11.95	17.07	14.51	11.95
	THRUST PER SCREW 10^4 lbs	21.6	18.0	H	27.6	H	H	32.4	H	H
	TOTAL THRUST 10^4 lbs	64.8	54.0	H	82.8	H	H	97.2	H	H
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.21	18.03	14.85	21.21	18.03	14.85	21.21	18.03	14.85
	THRUST PER SCREW 10^4 lbs	34.8	29.2	H	44.8	36.8	H	52.4	42.4	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.00	12.75	10.50	15.00	12.75	10.50	15.00	12.75	10.50
	THRUST PER SCREW 10^4 lbs	16.4	H	H	20.4	H	H	22.4	H	H
	TOTAL THRUST 10^4 lbs	67.6	—	—	85.6	—	—	97.2	—	—

H = P/D HIGHER THAN 1.40

TABLE 37 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: II PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.60	18.36	15.12	21.60	18.36	15.12	21.60	18.36	15.12
	THRUST PER SCREW 10^4 lbs	34.6	30.3	24.0	44.2	37.6	H	54.26	44.57	H
	TOTAL THRUST 10^4 lbs	68.2	60.6	48.0	88.4	75.2	—	108.54	89.14	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.07	14.51	11.95	17.07	14.51	11.95	17.07	14.51	11.95
	THRUST PER SCREW 10^4 lbs	22.1	18.1	H	27.6	H	H	32.5	H	H
	TOTAL THRUST 10^4 lbs	66.3	54.3	—	82.8	—	—	97.5	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.21	18.03	14.85	21.21	18.03	14.85	21.21	18.03	14.85
	THRUST PER SCREW 10^4 lbs	33.6	29.7	23.5	44.0	31.53	H	53.15	43.61	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.00	12.75	10.50	15.00	12.75	10.50	15.00	12.75	10.50
	THRUST PER SCREW 10^4 lbs	16.2	13.2	H	20.00	H	H	23.82	H	H
	TOTAL THRUST 10^4 lbs	66.0	56.1	—	84.0	—	—	100.79	—	—

H = P/D HIGHER THAN 1.40

TABLE 38 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: III PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	32.66	25.20	45.88	41.24	H	56.85	48.09	H
	TOTAL THRUST 10^4 lbs	—	75.32	50.4	91.76	82.48	—	113.70	96.18	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	23.7	21.0	15.20	32.22	25.73	H	37.81	29.17	H
	TOTAL THRUST 10^4 lbs	71.1	63.0	45.60	96.66	77.19	—	113.43	87.51	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	32.66	25.20	45.88	41.24	H	56.85	48.09	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.26	13.82	11.38	16.26	13.82	11.38	16.26	13.82	11.38
	THRUST PER SCREW 10^4 lbs	—	13.80	H	H	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	6076	—	—	—	—	—	—	—

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 39 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: III PROPELLER TYPE: B-3.65

APP.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	30.37	25.11	46.67	39.01	31.05	54.20	46.35	H
	TOTAL THRUST 10^4 lbs	—	60.74	50.22	93.34	78.02	62.10	108.40	92.70	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	23.2	20.01	15.65	29.73	25.62	H	35.60	29.81	H
	TOTAL THRUST 10^4 lbs	69.6	60.03	46.95	89.19	76.86	—	106.98	89.43	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	30.37	25.11	46.67	39.01	31.05	54.20	46.35	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.26	13.82	11.38	16.26	13.82	11.38	16.26	13.82	11.38
	THRUST PER SCREW 10^4 lbs	L	16.00	H	H	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	62.37	—	—	—	—	—	—	—

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 40 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: III PROPELLER TYPE: B4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	DIA %	100	85	70	100	85	70	100	85	70
	DIA FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	32.52	25.84	47.12	40.51	H	58.0	48.42	H
	TOTAL THRUST 10^4 lbs	—	65.04	51.68	94.24	81.02	—	116.0	96.84	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	24.6	20.83	H	31.81	26.40	13.51	37.07	29.72	H
	TOTAL THRUST 10^4 lbs	73.8	62.49	—	95.43	79.2	40.53	111.21	89.16	—
TRIPLE SCREW	SHP/SCREW	15,000			22,500			30,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	32.52	25.84	47.12	40.51	H	58.0	48.42	H
1:2:1	SHP/SCREW	7,500			11,250			15,000		
	DIA. %	100	85	70	100	85	70	100	85	70
	DIA. FT	16.26	13.82	11.38	16.26	13.82	11.38	16.26	13.82	11.38
	THRUST PER SCREW 10^4 lbs	—	—	—	H	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	—	—	H	—	—	—	—	—

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 41 COMPARISON OF THRUSTS

AHEAD OPERATION LIMIT DIAMETER

CASE: III PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	31.97	25.85	46.54	41.04	37.50	56.13	48.53	H
	TOTAL THRUST 10^4 lbs	—	63.94	51.7	93.08	82.08	65.00	102.26	97.06	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	23.8	21.05	16.53	31.73	26.33	H	37.58	30.91	H
	TOTAL THRUST 10^4 lbs	71.4	63.15	49.59	95.19	78.99	—	112.74	92.73	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	23.00	19.55	16.10	23.00	19.55	16.10	23.00	19.55	16.10
	THRUST PER SCREW 10^4 lbs	L	31.97	25.85	46.54	41.04	32.50	56.13	48.53	H
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.26	13.82	11.38	16.26	13.82	11.38	16.26	13.82	11.38
	THRUST PER SCREW 10^4 lbs	—	H	H	H	H	H	H	H	H
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	H	H

L = P/D LOWER THAN 0.50

H = P/D HIGHER THAN 1.40

TABLE 42 COMPARISON C

MAX SHP FOR NO-CAVITATION (ALL ARRANGEMENTS)

CASE	AVERAGE DIAMETERS		LIMIT DIAMETERS	
	B-3.65	B-4.70	B-3.65	B-4.70
I	15,750 [B]	15,200 [A]	21,300 [B]	19,200 [B]
II	23,250 [B]	21,000 [B]	29,700 [B]	29,700 [B]
III	31,875 [B]	31,500 [B,C]	37,800 [C]	37,200 [C]

A: TWIN SCREW ARR. STARTS FIRST TO CAVITATE

B: TRIPLE SCREW 1:1:1 -"- -"- -"- -"-

C: TRIPLE SCREW 1:2:1 -"- -"- -"- -"-

TABLE 43 CALCULATION OF $[T_{ASTERN} / T_{AHEAD}]$

PROPELLER TYPE	B-3.50	B-3.65	B-4.55	B-4.70
$l_{0.6R} / D$	.370	.481	.383	.501
$l_{0.7R} / l_{0.6R}$	.9919	.9919	.9808	.9808
$l_{0.7R} / D$	.369	.478	.376	.491
$S_{0.7R} / D$	.0171	.0171	.0156	.0156
$S_{0.7R} / l_{0.7R}$	.0465	.0358	.0415	.0317
$h_{0.7R} / l_{0.7R}$	.0233	.0179	.0208	.0159
$(C_T / C_Q)_{AHEAD}$	6.95	6.78	6.87	6.71
$(C_T / C_Q)_{ASTERN}$	5.44	5.61	5.51	5.68
T_{ASTERN} / T_{AHEAD}	.782	.827	.802	.846

Legend:

l = chord length, ft.

D = propeller diameter, ft.

S = blade thickness, ft

h = blade camber, ft

C_T = thrust coeff.

C_Q = torque coeff.

T = thrust, lbs

TABLE 44 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	13.8	11.0	—	20.1	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	27.6	22.0	—	40.2	—	—	—	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	8.5	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	25.5	—	—	—	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	14.1	11.8	—	21.0	—	—	25.2	—	—
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	6.0	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	26.1	—	—	—	—	—	—	—	—

TABLE 45 — COMPARISON OF THRUSTS

ASTERN OPERATION — AVERAGE DIAMETERS

CASE: III — PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	26.1	22.9	17.9	34.9	29.0	—	41.0	34.1	—
	TOTAL THRUST 10^4 lbs	52.2	45.8	35.8	69.8	58.0	—	82.0	68.2	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	17.3	14.8	—	22.5	18.2	—	26.9	—	—
	TOTAL THRUST 10^4 lbs	51.9	44.4	—	67.5	54.6	—	80.7	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.5	21.62	18.4	15.5	21.62	18.4	15.5
	THRUST PER SCREW 10^4 lbs	27.1	23.6	19.0	35.5	30.4	—	42.1	35.9	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	12.9	10.1	—	16.4	12.1	—	19.4	—	—
	TOTAL THRUST 10^4 lbs	52.9	43.8	—	68.3	54.6	—	80.9	—	—

TABLE 46 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B 4.55

	SHP TOTAL		15,000			30,000			45,000	
TWIN SCREW	SHP/SCREW		7,500			15,000			22,500	
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs		14.0	11.3	—	21.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs		28.0	22.6	—	42.0	—	—	—	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW		10,000			15,000			20,000		
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs		9.0	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs		27.0	—	—	—	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW		7,500			15,000			22,500		
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs		14.3	12.2	—	22.0	—	—	26.8	—	—
	SHP/SCREW		3,750			7,500			11,250		
		%	100	85	70	100	85	70	100	85	70
	DIA.	FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs		—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs		—	—	—	—	—	—	—	—	—

TABLE 47 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: I PROPELLER TYPE: B-4.70

	SHP TOTAL / AER.	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	14.9	12.2	—	22.0	—	—	27.6	—	—
	TOTAL THRUST 10^4 lbs	29.8	24.4	—	44.0	—	—	55.2	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	9.6	—	—	14.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	28.8	—	—	42.0	—	—	—	—	—
TRIPLE SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	15.2	12.9	—	23.0	18.6	—	29.0	—	—
1:2:1	SHP/SCREW	3,750			7500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 48 — COMPARISON OF THRUSTS

ASTERN OPERATION — AVERAGE DIAMETERS

CASE: II — PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	24.0	19.0	—	29.9	—	—	34.1	—	—
	TOTAL THRUST 10^4 lbs	48.0	38.0	—	59.8	—	—	68.2	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	15.2	—	—	18.1	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	45.6	—	—	54.3	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	25.0	20.2	—	31.7	—	—	36.2	—	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	10.2	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	45.4	—	—	—	—	—	—	—	—

TABLE 49 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: II PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	23.8	20.1	—	30.5	25.0	—	36.0	—	—
	TOTAL THRUST 10^4 lbs	47.6	40.2	—	61.0	50.0	—	72.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	15.4	12.0	—	19.5	—	—	22.7	—	—
	TOTAL THRUST 10^4 lbs	46.2	36.0	—	58.5	—	—	68.1	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	24.8	21.0	—	31.4	26.0	—	37.9	—	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	11.0	—	—	13.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	46.8	—	—	57.4	—	—	—	—	—

TABLE 50 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: II PROPELLER TYPE: B-4.55

SHP TOTAL APP.		30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	24.6	19.9	—	31.0	—	—	35.9	—	—
	TOTAL THRUST 10^4 lbs	49.2	39.8	—	62.0	—	—	71.8	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	15.9	—	—	19.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	47.7	—	—	57.0	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	25.6	21.2	—	32.0	—	—	37.8	—	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	11.1	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	47.8	—	—	—	—	—	—	—	—

TABLE 51 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: II PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	25.8	21.4	—	32.5	26.5	—	38.1	—	—
	TOTAL THRUST 10^4 lbs	51.6	42.8	—	65.0	53.0	—	76.2	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82			
	THRUST PER SCREW 10^4 lbs	16.6	13.4	—	20.8	—	—	24.0	—	—
	TOTAL THRUST 10^4 lbs	49.8	40.2	—	62.4	—	—	72.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	26.5	22.2	—	34.0	27.9	—	39.9	32.0	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	12.4	—	—	15.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	50.7	—	—	64.0	—	—	—	—	—

TABLE 52 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	25.9	23.0	—	34.4	28.0	—	41.0	32.0	—
	TOTAL THRUST 10^4 lbs	51.8	46.0	—	68.8	56.0	—	82.0	64.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	17.6	14.1	—	22.2	—	—	25.5	—	—
	TOTAL THRUST 10^4 lbs	52.8	42.3	—	66.6	—	—	76.5	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	26.8	23.8	—	35.2	29.8	—	42.8	34.0	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	13.0	—	—	16.0	—	—	17.9	—	—
	TOTAL THRUST 10^4 lbs	52.8	—	—	67.2	—	—	78.6	—	—

TABLE 53 — COMPARISON OF THRUSTS

ASTERN OPERATION — *AVERAGE DIAMETERS*

CASE: *I* — PROPELLER TYPE: *B-3.65*

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	13.4	11.5	—	20.9	16.0	—	25.9	—	—
	TOTAL THRUST 10^4 lbs	26.8	23.0	—	41.8	32.0	—	51.8	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	8.9	—	—	12.8	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	26.7	—	—	38.4	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	13.8	12.0	—	21.7	17.1	—	27.5	—	—
	SHP/SCREW	3,750			7500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 54 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-4,55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	27.2	23.7	—	35.1	29.3	—	41.3	33.8	—
	TOTAL THRUST 10^4 lbs	54.4	47.4	—	70.2	58.6	—	82.6	67.6	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	18.0	14.7	—	23.0	—	—	27.0	—	—
	TOTAL THRUST 10^4 lbs	54.0	44.1	—	69.0	—	—	81.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	28.0	24.4	18.2	36.6	30.9	—	43.2	35.5	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	13.2	10.2	—	16.5	—	—	18.4	—	—
	TOTAL THRUST 10^4 lbs	54.4	44.8	—	69.6	—	—	80.0	—	—

TABLE 55 COMPARISON OF THRUSTS

ASTERN OPERATION AVERAGE DIAMETERS

CASE: III PROPELLER TYPE: B-4,70

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	28.0	24.9	19.0	37.0	31.1	—	44.2	36.5	—
	TOTAL THRUST 10^4 lbs	56.0	49.8	38.0	74.0	62.2	—	88.4	73.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	18.9	15.9	—	24.0	19.8	—	28.3	—	—
	TOTAL THRUST 10^4 lbs	56.7	47.7	—	72.0	59.4	—	84.9	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	29.5	25.6	20.2	37.6	32.4	—	45.8	38.0	—
	SHP/SCREW	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	14.0	11.4	—	17.7	—	—	20.4	—	—
	TOTAL THRUST 10^4 lbs	57.5	48.4	—	73.0	—	—	86.6	—	—

TABLE *56* COMPARISON OF THRUSTS

AHEAD OPERATION *COMPROMISE PROPELLER*

CASE: *I* PROPELLER TYPE: *B-3.50*

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	15.7	12.4	—	22.6	—	—	27.5	—	—
	TOTAL THRUST 10^4 lbs	31.4	24.8	—	45.2	—	—	55.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	9.8	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	29.4	—	—	—	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	16.0	13.2	—	24.0	—	—	28.9	—	—
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 57 COMPARISON OF THRUSTS

AHEAD OPERATION COMPROMISE PROPELLER

CASE: I PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	15.0	12.9	—	23.0	—	—	28.5	—	—
	TOTAL THRUST 10^4 lbs	30.0	29.8	—	46.0	—	—	57.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	10.00	—	—	14.0	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	30.0	—	—	42.0	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	15.5	13.1	—	23.8	19.0	—	29.9	—	—
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 58 — COMPARISON OF THRUSTS

AHEAD OPERATION — COMPROMISE PROPELLER

CASE: I — PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	15,000			30,000			45,000.		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	15.9	12.9	—	23.3	—	—	28.0	—	—
	TOTAL THRUST 10^4 lbs	31.8	25.8	—	46.6	—	—	56.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5,000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.5	11.48	9.45	13.5	11.48	9.45
	THRUST PER SCREW 10^4 lbs	10.0	—	—	14.1	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	30.0	—	—	42.3	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	16.3	13.6	—	24.5	—	—	30.0	—	—
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 59 COMPARISON OF THRUSTS

AHEAD OPERATION COMPROMISE PROPELLER

CASE: I PROPELLER TYPE: B-4.70

ARR.	SHP TOTAL	15,000			30,000			45,000		
TWIN SCREW	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.25	13.81	11.37	16.25	13.81	11.37	16.25	13.81	11.37
	THRUST PER SCREW 10^4 lbs	16.2	13.8	—	24.1	—	—	30.2	—	—
	TOTAL THRUST 10^4 lbs	32.4	27.6	—	48.2	—	—	60.4	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	5000			10,000			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.5	11.48	9.45	13.8	11.48	9.45	13.8	11.48	9.45
	THRUST PER SCREW 10^4 lbs	10.6	—	—	15.2	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	31.8	—	—	45.6	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW	7,500			15,000			22,500		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	16.88	14.35	11.8	16.88	14.35	11.8	16.88	14.35	11.8
	THRUST PER SCREW 10^4 lbs	16.6	14.2	—	25.1	20.1	—	31.5	—	—
	SHP/SCREW	3,750			7,500			11,250		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	11.81	10.01	8.27	11.81	10.01	8.27	11.81	10.01	8.27
	THRUST PER SCREW 10^4 lbs	—	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	—	—	—	—	—	—	—	—	—

TABLE 60 — COMPARISON OF THRUSTS

AHEAD — COMPROMISE

CASE. 11 — PROPELLER TYPE: B-350

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	1856	15.8	13.0	18.56	15.8	13.0	18.56	15.8	130
	THRUST PER SCREW 10^4 lbs	27.2	21.5	—	34.0	—	—	39.0	—	—
	TOTAL THRUST 10^4 lbs	54.4	43.0	—	68.0	—	—	78.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	17.0	—	—	20.3	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	51.0	—	—	60.9	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	28.3	22.9	—	35.9	27.6	—	41.2	—	—
	SHP/SCREW OS	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	12.1	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	52.5	—	—	—	—	—	—	—	—

TABLE 61 COMPARISON OF THRUSTS

AHEAD COMPROMISE

CASE: 11 PROPELLER TYPE:

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	26.1	22.0	—	33.8	27.2	—	40.0	—	—
	TOTAL THRUST 10^4 lbs	52.2	44.0	—	67.6	54.4	—	80.0	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	17.1	13.2	—	21.5	—	—	24.8	—	—
	TOTAL THRUST 10^4 lbs	51.3	39.6	—	64.5	—	—	74.4	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	27.2	23.1	—	35.0	28.6	—	41.8	—	—
	SHP/SCREW OS	7500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	12.2	—	—	14.8	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	51.6	—	—	64.6	—	—	—	—	—

TABLE 62

AHEAD

CASE: 11

COMPARISON OF THRUSTS

COMPROMISE

PROPELLER TYPE:

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	27.4	22.1	—	34.9	—	—	40.3	—	—
	TOTAL THRUST 10^4 lbs	54.8	44.2	—	69.8	—	—	80.6	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	17.5	—	—	21.2	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	52.5	—	—	63.6	—	—	—	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	16.44
	THRUST PER SCREW 10^4 lbs	28.8	23.5	—	36.1	28.0	—	42.9	—	—
	SHP/SCREW OS	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	12.2	—	—	—	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	53.2	—	—	—	—	—	—	—	—

TABLE 63 COMPARISON OF THRUSTS

AHEAD COMPROMISE

CASE: 11 PROPELLER TYPE: B-4.7

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	18.56	15.8	13.0	18.56	15.8	13.0	18.56	15.8	13.0
	THRUST PER SCREW 10^4 lbs	28.0	23.5	—	35.9	29.0	—	41.9	—	—
	TOTAL THRUST 10^4 lbs	56.0	47.0	—	71.8	58.0	—	83.8	—	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.46	13.14	10.82	15.46	13.14	10.82	15.46	13.14	10.82
	THRUST PER SCREW 10^4 lbs	18.0	14.6	—	22.8	—	—	26.2	—	—
	TOTAL THRUST 10^4 lbs	54.0	43.8	—	68.4	—	—	78.6	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	19.20	16.32	13.44	19.20	16.32	13.44	19.20	16.32	13.44
	THRUST PER SCREW 10^4 lbs	29.0	24.2	—	37.1	30.6	—	43.8	—	—
	SHP/SCREW OS	7500			11,250			15000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	13.6	11.56	9.53	13.6	11.56	9.53	13.6	11.56	9.53
	THRUST PER SCREW 10^4 lbs	13.3	—	—	16.2	—	—	—	—	—
	TOTAL THRUST 10^4 lbs	55.6	—	—	69.5	—	—	—	—	—

TABLE 64 COMPARISON OF THRUSTS

STERN COMPROMISE

CASE: III PROPELLER TYPE: B-3.50

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	29.6	26.0	—	39.2	31.9	—	46.5	36.0	—
	TOTAL THRUST 10^4 lbs	59.2	52.0	—	78.4	63.8	—	93.0	72.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	20.1	16.0	—	25.1	—	—	29.0	—	—
	TOTAL THRUST 10^4 lbs	60.3	48.0	—	75.3	—	—	87.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	30.2	27.0	20.0	40.0	33.8	—	48.2	38.8	—
	SHP/SCREW OS	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	14.4	11.5	—	18.0	—	—	20.2	—	—
	TOTAL THRUST 10^4 lbs	59.0	50.0	—	76.0	—	—	88.6	—	—

TABLE 65 COMPARISON OF THRUSTS

STERN COMPROMISE

CASE: III PROPELLER TYPE: B-3.65

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	29.0	25.0	19.6	37.8	32.3	—	45.0	38.0	—
	TOTAL THRUST 10^4 lbs	58.0	50.0	39.2	75.6	64.6	—	90.0	76.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	19.2	16.1	—	24.6	20.1	—	29.1	—	—
	TOTAL THRUST 10^4 lbs	57.6	48.3	—	73.8	60.3	—	87.3	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	30.0	26.0	21.0	39.0	33.7	—	46.2	39.9	—
	SHP/SCREW OS	7,500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	14.3	11.2	—	18.2	13.6	—	21.2	—	—
	TOTAL THRUST 10^4 lbs	58.6	48.4	—	75.4	60.9	—	88.6	—	—

TABLE 66 COMPARISON OF THRUSTS

STERN COMPROMISE

CASE: 111 PROPELLER TYPE: B-4.55

ARR.	SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW	SHP/SCREW	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
	THRUST PER SCREW 10^4 lbs	30.7	26.0	—	39.8	33.0	—	46.8	37.5	—
	TOTAL THRUST 10^4 lbs	61.4	52.0	—	79.6	66.0	—	93.6	75.0	—
TRIPLE SCREW 1:1:1	SHP/SCREW	10,000			15,000			20,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
	THRUST PER SCREW 10^4 lbs	20.0	16.6	—	25.6	19.9	—	30.0	—	—
	TOTAL THRUST 10^4 lbs	60.0	49.8	—	76.8	59.7	—	90.0	—	—
TRIPLE SCREW 1:2:1	SHP/SCREW CS	15,000			22,500			30,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
	THRUST PER SCREW 10^4 lbs	31.3	27.0	20.3	41.0	34.8	—	48.4	40.0	—
	SHP/SCREW OS	7500			11,250			15,000		
	%	100	85	70	100	85	70	100	85	70
	DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
	THRUST PER SCREW 10^4 lbs	15.0	11.3	—	18.6	—	—	20.5	—	—
	TOTAL THRUST 10^4 lbs	61.3	49.6	—	78.2	—	—	89.4	—	—

TABLE 67 COMPARISON OF THRUSTS

STERN COMPRMISE

CASE: III PROPELLER TYPE: B-4.70

AR3.		SHP TOTAL	30,000			45,000			60,000		
TWIN SCREW		SHP/SCREW	15,000			22,500			30,000		
		%	100	85	70	100	85	70	100	85	70
		DIA. FT	20.88	17.8	14.65	20.88	17.8	14.65	20.88	17.8	14.65
		THRUST PER SCREW 10^4 lbs	30.5	27.0	21.0	40.0	34.0	—	48.0	40.0	—
		TOTAL THRUST 10^4 lbs	61.0	54.0	42.0	80.0	68.0	—	96.0	80.0	—
TRIPLE SCREW 1:1:1		SHP/SCREW	10,000			15,000			20,000		
		%	100	85	70	100	85	70	100	85	70
		DIA. FT	17.4	14.8	12.2	17.4	14.8	12.2	17.4	14.8	12.2
		THRUST PER SCREW 10^4 lbs	20.5	17.0	—	26.4	21.2	—	31.0	—	—
		TOTAL THRUST 10^4 lbs	61.5	51.0	—	79.2	63.6	—	93.0	—	—
TRIPLE SCREW 1:2:1	CS	SHP/SCREW	15000			22,500			30,000		
		%	100	85	70	100	85	70	100	85	70
		DIA. FT	21.62	18.4	15.15	21.62	18.4	15.15	21.62	18.4	15.15
		THRUST PER SCREW 10^4 lbs	32.0	27.9	22.0	41.0	35.5	—	49.6	41.6	—
	OS	SHP/SCREW	7500			11,250			15,000		
		%	100	85	70	100	85	70	100	85	70
		DIA. FT	15.29	13.0	10.7	15.29	13.0	10.7	15.29	13.0	10.7
		THRUST PER SCREW 10^4 lbs	15.1	12.6	—	19.2	—	—	22.2	—	—
		TOTAL THRUST 10^4 lbs	62.2	53.1	—	79.4	—	—	94.0	—	—

TABLE 68 SAMPLE CALCULATION

EFFICIENCY AT SPEED OF ADVANCE OF 1 KNOT

Taking case I, twin screw arrangement - we define the diameter of the screws

$D = 16.25$ ft. - for average D_{max}. (Table 1)

If we choose $SHP_{TOTAL} = 15000$ - we define the pitch-ratio used for this arrangement at bollard condition.

From table 74 $P/D = 0.790$

$$\frac{SHP}{screw} = \frac{15000}{2} = 7{,}500$$

(a) $$J = \frac{V_a}{n\,D} = \frac{1\text{ knot} \cdot 1.689 \frac{ft/sec}{knot}}{2\text{ rps} \times 16.25\text{ ft}} = 0.0468$$

We found in table 3 that:

(b) $$K_Q = 43.97 \frac{SHP}{n^3 D^5}$$, so we calculate now:

$$K_Q = \frac{43.97 \times 7500}{2^3 \times (16.25)^5} = 0.0367$$

But for the above J and P/D we read from Henschke's diagram that

$K_Q = 0.0363$.

We must change the n so that the 2 values of K_Q will be equal.

For $n = 121$ rpm, $K_Q = 0.0356$, by equation (b)

TABLE 69 SAMPLE CALCULATION (cont'd)

Interpolation of n values in order to get equal K_Q from calculation and graph gives that equilibrium is reached at $n = 120.27 \sim 120$ rpm.

Conclusion: As equilibrium rpm is very close to 120 rpm, we shall assume that all propellers work at 120 at a speed of advance of one knot, the same as in the bollard condition.

For $J = 0.0468$, $P/D = 0.79$, we find from Henschke's diagram that

η_0 = open water efficiency = 6.%

In order to find the propulsive efficiency, we must calculate the hull efficiency η_H, as $\eta_P = \eta_0 \eta_H \eta_R$.

We assume $\eta_R = 1.0$ for all screws.

For the calculation of η_H, the following values of wake fraction and thrust deduction were assumed:

screw	wake fraction (w)	thrust deduction (t)
center	0.04	0.03
outboard	0.10	0.10

TABLE 70 SAMPLE CALCULATION (cont'd)

$$\eta_{H_i} = \frac{1-t_i}{1-w_i}$$ can be found for each screw

$$\eta_{H_{c.s}} = \frac{1-0.03}{1-0.04} = \frac{0.97}{0.96}$$ (center screw)

$$\eta_{H_{o.s}} = \frac{1-0.10}{1-0.10} = \frac{0.90}{0.90} = 1$$ (out board screw)

For the combination of screws in the different arrangements, we use

$$\eta_{H\,TOTAL} = \frac{1}{\sum \frac{SHP_i}{SHP_{TOTAL}} \frac{1}{\eta_{Hi}}}$$

(a) Twin Screw

$$\eta_{H\,total} = \frac{1}{\frac{1}{2}\cdot 1 + \frac{1}{2}\cdot 1} = 1.00$$

(b) Triple screw 1:1:1

$$\eta_{H\,total} = \frac{1}{\underbrace{\frac{1}{3}\,\frac{0.96}{0.97}}_{c.s} + \underbrace{2\cdot\frac{1}{3}\cdot 1}_{o.s}} = \frac{3}{2.991} = 1.003 \sim 1.0$$

(c) Triple screw 1:2:1

$$\eta_{H\,total} = \frac{1}{\frac{1}{2}\cdot\frac{0.96}{0.97} + 2\times\frac{1}{4}\cdot 1} = \frac{2}{1.991} = 1.0045 \sim 1.0$$

Conclusion: As all η_H are close to unity we can use $\eta_p = \eta_o$ for all arrangements

TABLE 71

Efficiency at V_a = 1 knot (n = 120 RPM) (AVERAGE DIA.)

ARR.	CASE	DIA. [ft], J	SHP max TOTAL	B-3.50 P/D	B-3.50 η_p %	B-3.65 P/D	B-3.65 η_p %	B-4.55 P/D	B-4.55 η_p %	B-4.70 P/D	B-4.70 η_p %
TWIN SCREW	I	16.25'	15000	.790	7.2	.730	7.1	.740	7.7	.741	7.6
		.0520	30000	1.115	5.1	1.042	5.7	1.106	[illegible]	1.036	5.9
			45000	H	—	1.294	4.8	H	—	1.247	4.9
	II	18.56	30,000	.801	6.8	.741	6.2	.751	6.6	.752	6.6
		.0455	45,000	.971	5.6	.910	5.2	.952	5.4	.921	5.7
			60,000	1.135	4.5	1.057	4.8	1.124	5.2	1.050	5.0
	III	20.88'	30,000	.576	6.6	.551	6.6	.546	7.3	.548	7.2
		.0404	45,000	.726	6.0	.674	5.9	.692	6.4	.684	6.3
			60,000	.843	5.2	.785	5.0	.795	5.7	.791	5.6
TRIPLE SCREW (1:1:1)	I	13.50'	15,000	1.015	6.7	.953	7.0	1.003	7.5	.958	7.3
		.0626	30,000	H	—	1.369	5.2	H	—	[illegible]	5.5
			45,000	H	—	H	—	H	—	H	—
	II	15.46'	30,000	1.023	5.9	.961	6.1	1.012	6.5	.965	6.4
		.0546	45,000	1.300	4.7	[illegible]	5.3	[illegible]	5.4	[illegible]	5.4
			60,000	H	—	[illegible]	4.7	H	—	[illegible]	[illegible]
	III	17.40'	30,000	.767	6.9	.708	6.8	.718	7.2	.721	7.1
		.0485	45,000	.933	5.7	[illegible]	5.8	.907	6.0	[illegible]	6.1
			60,000	1.081	5.0	1.014	5.2	1.072	5.7	[illegible]	5.5
CENTER SCREW (1:2:1)	I	16.88'	15,000	.711	7.5	.663	7.5	.669	7.6	.672	7.8
		.0500	30,000	1.005	5.6	.944	5.6	[illegible]	6.2	.950	6.0
			45,000	1.273	4.4	1.166	5.0	1.258	5.2	[illegible]	[illegible]
	II	19.20'	30,000	.731	6.9	.678	6.6	.687	6.8	.690	6.7
		.0440	45,000	.895	5.6	[illegible]	5.4	[illegible]	5.9	[illegible]	5.9
			60,000	1.032	4.8	.969	5.0	1.020	5.4	[illegible]	5.2
	III	21.62	30,000	.524	7.2	.501	7.0	.490	—	.498	7.6
		.0391	45,000	.650	6.1	[illegible]	6.0	[illegible]	6.5	[illegible]	6.5
			60,000	.773	5.6	.713	5.3	.773	5.7	.726	[illegible]
OUTBOARD SCREW (1:2:1)	I	11.81'	15,000	1.269	6.6	1.163	6.9	1.253	7.2	1.142	7.0
		.0715	30,000	H	—	H	—	H	—	H	—
			45,000	H	—	H	—	H	—	H	—
	II	13.60'	30,000	1.260	5.6	1.155	6.0	1.243	6.3	1.135	6.0
		.0621	45,000	H	—	H	—	H	—	1.368	—
			60,000	H	—	H	—	H	—	H	—
	III	15.29'	30,000	.912	5.7	.855	6.4	.882	7.0	.864	6.9
		.0552	45,000	1.127	5.5	1.051	5.7	1.117	6.1	1.044	6.0
			60.000	1.244	4.7	1.225	5.3	[illegible]	6.3	[illegible]	5.3
TRIPLE SCREW (1:2:1) COMBINED	I	16.88' / 11.81'	15,000	—	7.0	—	7.2	—	7.5	—	7.4
			30,000	—	—	—	—	—	—	—	—
			45,000	—	—	—	—	—	—	—	—
	II	19.20' / 13.60'	30,000	—	6.2	—	6.3		6.6	—	6.4
			45,000	—	—	—	—	—	—	—	—
			60,000	—	—	—	—	—	—	—	—
	III	21.62' / 15.29'	30,000	—	6.4	—	6.7	—	—	—	7.0
			45,000	—	6.1	—	6.7	—	6.2	—	6.2
			60,000	—	[illegible]	—	5.3	—	[illegible]	—	[illegible]

FIG 72

EFFICIENCY AT V_A = 1 KNOT (n = 120 RPM) (LIMIT DIA.)

ARR	CASE	DIA [FT] J	SHP MAX TOTAL	B-3.50 P/D	B-3.50 η_p%	B-3.65 P/D	B-3.65 η_p%	B-4.55 P/D	B-4.55 η_p%	B-4.70 P/D	B-4.70 η_p%
TWIN SCREW	I	18.90	15000	.520	7.8	.495	L	L	—	.492	—
			30,000	.764	6.2	.705	6.2	.715	7.0	.718	6.25
		.0446	45000	.929	5.4	.871	5.1	.903	6.2	.881	5.3
	II	21.60	30,000	.525	7.0	.502	7.0	.492	L	.499	7.0
			45,000	.652	5.9	.621	5.9	.624	6.5	.624	6.0
		.0390	60,000	.775	5.5	.715	5.0	.725	6.0	.728	5.0
	III	23.0	30,000	L	—	L	—	L	—	L	—
			45000	.546	6.0	.528	6.0	.521	7.5	.525	6.3
		.0367	60,000	.641	5.3	.613	5.2	.615	6.4	.615	5.5
TRIPLE SCREW (1:1:1)	I	14.93	15,000	.797	7.5	.737	7.5	.747	8.0	.748	7.6
			30,000	1.128	5.7	1.052	5.7	1.118	6.3	1.045	6.0
		.0565	45,000	H	—	1.307	4.99	H	—	1.257	5.0
	II	17.07	30,000	.807	6.5	.747	6.5	.756	7.5	.757	6.9
			45,000	.978	5.5	.916	5.5	.960	6.3	.926	5.8
		.0495	60,000	1.144	5.0	1.064	5.3	1.133	6.0	1.057	4.99
	III	19.20	30,000	.571	7.6	.555	7.0	.550	8.1	.552	7.5
			45 000	.732	6.5	.679	6.0	.687	7.2	.690	6.4
		.0430	60,000	.848	5.7	.791	5.5	.801	6.5	.797	6.0
CENTER SCREW (1:2:1)	I	18.56	15,000	.539	8.4	.521	7.4	.512	9.0	.517	9.0
			30,000	.801	6.0	.741	6.0	.751	7.4	.752	6.8
		.0455	45 000	.971	5.7	.910	5.4	.953	6.0	.921	5.9
	II	21.21	30,000	.545	6.8	.528	6.5	.521	7.4	.524	6.8
			45,000	.692	6.0	.649	5.4	.655	6.3	.656	5.9
		.0397	60,000	.812	5.2	.752	5.0	.762	5.9	.761	5.0
	III	23.0	30,000	L	—	L	—	L	—	L	—
			45000	.546	6.0	.528	6.0	.521	7.5	.525	6.3
		.0367	60, 000	.641	5.3	.613	5.2	.615	6.4	.615	5.5
OUTBOARD SCREW (1:2:1)	I	13.12	15 000	.944	7.6	.884	7.4	.921	8.5	.896	7.9
			30,000	1.40	5.2	1.275	5.3	1.40	6.0	1.231	5.7
		.0643	45 000	H		H	—	H	—	H	—
	II	15.0	30,000	.955	6.7	.894	6.1	.934	7.0	.906	7.0
			45,000	1.195	5.3	1.103	5.1	1.180	6.1	1.092	5.3
		.0562	60,000	H	—	1.291	4.9	H		1.244	4.9
	III	16.27	30,000	.712	7.4	.664	7.5	.670	8.0	.673	7.5
			45000	.956	6.1	.895	5.8	.935	6.5	.907	6.0
		.0519	60,000	1.007	5.9	.945	5.7	.994	6.3	.952	5.8
TRIPLE SCREW (1:2:1) COMBINED	I	18.56	15,000	—	8.3	—	7.4	—	8.75	—	8.0
		13.12	30,000	—	5.6	—	5.6	—	6.65	—	6.2
			45000	—		—		—		—	
	II	21.21	30,000	—	6.75	—	6.3	—	7.2	—	6.9
		15.0	45,000	—	5.6	—	5.25	—	6.2	—	5.6
			60,000	—		—	4.95	—		—	4.95
	III	23.0	30,000	—	—	—		—	—	—	—
		16.27	45,000	—	6.05	—	5.9	—	7.0	—	6.15
			60,000	—	5.6	—	5.45	—	6.35	—	5.65

TABLE 73

"Ehp Estimation"

Ayre:

$$Ehp = \frac{550}{76.0} \cdot \frac{D^{0.64} \cdot V^3_{m/sec}}{C}$$

$$= \frac{75}{76} \cdot \frac{D^{0.64} \, V^3_{knots}}{C}$$

$$= 0.985 \, \frac{D^{0.64} \, V^3}{C}$$

DETERMINATION of C.

CASE L x B/3 x H	D = Disp metric tons	$D^{0.64}$	$D^{1/3}$	$F = \frac{0.514 \times 18}{\sqrt{9.81 \times LWL \times 0.305}}$	F	$\frac{LWL\ (meters)}{D^{1/3}}$	C
1 300'x70'x23'	8,600	420	20.5	$\frac{0.514 \cdot 18}{\sqrt{9.81 \times 300 \times 0.305}} = 0.3$	0.31	4.46	230
2 350'x80'x30'	12,200	530	23	$= \frac{9.28}{32.2} = 0.288$	0.288	4.6	280
3 400'x90'x30'	15,600	612	25	$= 9.28/34.5 = 0.268$	0.268	4.86	330

V^3_{knots}	$D^{0.64}$	C	Ehp
5,900	420	230	10,600
5,900	530	280	11,000
5,900	612	330	10,800

TABLE 74 PITCH RATIOS FOR BOLLARD OPERATION (AVERAGE DIAMETERS)

Max Total SHP CASE I	Max Total SHP CASE II III	SCREW TYPE	TWIN SCREW CASE I D = 16.25'	TWIN SCREW CASE II D = 18.56'	TWIN SCREW CASE III D = 20.88'	TRIPLE SCREW 1:1:1 CASE I D = 13.5'	TRIPLE SCREW 1:1:1 CASE II D = 15.46'	TRIPLE SCREW 1:1:1 CASE III D = 17.4'	TRIPLE SCREW 1:2:1 CENTER SCREW CASE I D = 16.88	TRIPLE SCREW 1:2:1 CENTER SCREW CASE II D = 19.2'	TRIPLE SCREW 1:2:1 CENTER SCREW CASE III D = 21.62'	TRIPLE SCREW 1:2:1 OUT BOARD SCREW CASE I D = 11.81'	TRIPLE SCREW 1:2:1 OUT BOARD SCREW CASE II D = 13.6'	TRIPLE SCREW 1:2:1 OUT BOARD SCREW CASE III D = 15.29
15,000	30,000	B 3.50	.740	.801	.567	1.015	1.023	.767	.711	.731	.524	1.269	1.260	.912
		B 3.65	.730	.741	.551	.953	.961	.708	.663	.678	.501	1.163	1.155	.855
		B 4.55	.740	.751	.546	1.003	1.012	.714	.671	.657	L	1.253	1.243	.862
		B 4.70	.741	.752	.548	.958	.965	.721	.672	.690	.498	1.142	1.136	.861
30,000	45,000	B 3.50	1.115	.971	.726	H	1.300	.938	1.005	.896	.690	H	H	1.127
		B 3.65	1.067	.915	.674	1.369	1.188	.874	.934	.839	.622	H	H	1.051
		B 4.55	1.106	.952	.682	H	1.257	.907	.992	.860	.622	H	H	1.117
		B 4.70	1.036	.921	.689	1.212	1.163	.884	.920	.846	.622	H	1.363	1.044
45,000	60,000	B 3.50	H	1.135	.893	H	H	1.081	1.273	1.002	.773	H	H	1.344
		B 3.65	1.199	1.057	.785	H	1.318	1.014	1.112	.969	.713	H	H	1.225
		B 4.55	H	1.124	.795	H	H	1.072	1.158	1.020	.723	H	H	1.335
		B 4.70	1.247	1.050	.791	H	1.311	1.010	1.195	.972	.725	H	H	1.193
$(\frac{SHP}{SCREW}) / (SHP_{MAX})_{TOTAL}$			0.50			0.333			0.50			0.25		

TABLE 75 PITCH RATIOS FOR BOLLARD CONDITION (LIMIT DIAMETERS)

Max Total SHP CASE I	Max Total SHP CASE II & III	SCREW TYPE	TWIN SCREW CASE I D=18.90'	TWIN SCREW CASE II D=21.60'	TWIN SCREW CASE III D=23.0'	TRIPLE SCREW (1:1:1) CASE I D=14.93'	TRIPLE SCREW (1:1:1) CASE II D=17.0'	TRIPLE SCREW (1:1:1) CASE III D=19.20'	TRIPLE SCREW 1:2:1 CENTER SCREW CASE I D=18.56'	TRIPLE SCREW 1:2:1 CENTER SCREW CASE II D=21.21'	TRIPLE SCREW 1:2:1 CENTER SCREW CASE III D=23.0'	TRIPLE SCREW 1:2:1 OUTBOARD SCREWS CASE I D=13.12'	TRIPLE SCREW 1:2:1 OUTBOARD SCREWS CASE II D=15.0'	TRIPLE SCREW 1:2:1 OUTBOARD SCREWS CASE III D=16.27'
15,000	30,000	B-3.50	.520	.525	L	.797	.807	.571	.539	.545	L	.944	.955	.712
		B-3.65	.495	.502	L	.737	.747	.555	.521	.528	L	.884	.894	.664
		B-4.55	L	.492	L	.747	.756	.550	.512	.521	L	.921	.934	.670
		B-4.70	.492	.499	L	.748	.757	.552	.517	.524	L	.896	.906	.673
30,000	45,000	B-3.50	.764	.652	.546	1.128	.978	.732	.801	.692	.546	1.40	1.195	.956
		B-3.65	.705	.621	.528	1.052	.916	.679	.741	.649	.528	1.275	1.163	.895
		B-4.55	.715	.624	.521	1.118	.960	.687	.751	.655	.521	1.40	1.180	.935
		B-4.70	.718	.624	.525	1.045	.926	.690	.752	.656	.525	1.231	1.092	.907
45,000	60,000	B-3.50	.929	.775	.641	H	1.144	.848	.971	.812	.641	H	H	1.007
		B-3.65	.871	.715	.613	1.307	1.064	.791	.910	.752	.613	H	1.291	.945
		B-4.55	.903	.725	.615	H	1.133	.801	.953	.762	.615	H	H	.994
		B-4.70	.881	.728	.615	1.257	1.057	.797	.921	.761	.615	H	1.244	.952
(SHP/SCREW)/(SHP total)			0.50			0.33			0.50			0.25		

TABLE 76 SAMPLE CALCULATION

PROPULSIVE EFFICIENCY AT SPEED OF 18 KNOTS

1. Calculation of the open water efficiency (η_o)

The procedure is similar to the one used for finding η_o at a speed of advance of one knot.

Using the same system, ie twin screw arrangement in case I and $SHP_{TOTAL} = 15000$ we have again $D = 16.25$ ft, $P/D = 0.790$

Let's find the efficiency at a free-running SHP of 12000

Now we have to take in account the wake fraction, as 18 knots is ship speed and not speed of advance.

The following values were used for wake fraction and thrust deduction

Screw	wake fraction (w)	Thrust deduction (t)
Center screw	0.25	0.15
Outboard Screw	0.10	0.10

We find $J = \dfrac{V_a}{nD} = \dfrac{V_s(1-w)}{nD}$, at $n = 140$ rpm:

$$J = \frac{18 \text{ knots} \cdot 1.689 \frac{ft/sec}{knot} \cdot (1-0.1)}{(140/60) \cdot 16.25} = 0.722$$

$$K_Q = \frac{43.97 \cdot SHP}{n^3 D^5} = \frac{43.97 \cdot 12000}{(140/60)^3 \cdot 16.25^5} = 0.0180$$

TABLE 77 SAMPLE CALCULATION (cont'd)

For the above J and P/D, we get from Henschke's chart for a B-3.50 propeller that $K_Q = 0.0104$, which is not equal to the calculated K_Q at 140 rpm.

Let's try n = 160 rpm, for which we can find: J = 0.631, $K_Q = 0.0120$, and again from the chart, for the new J we find $K_Q = 0.0150$.

To summarize, we found.

n	K_Q (calculated)	K_Q (from chart)	J
140	0.0180	0.0104	0.722
160	0.0120	0.0150	0.631

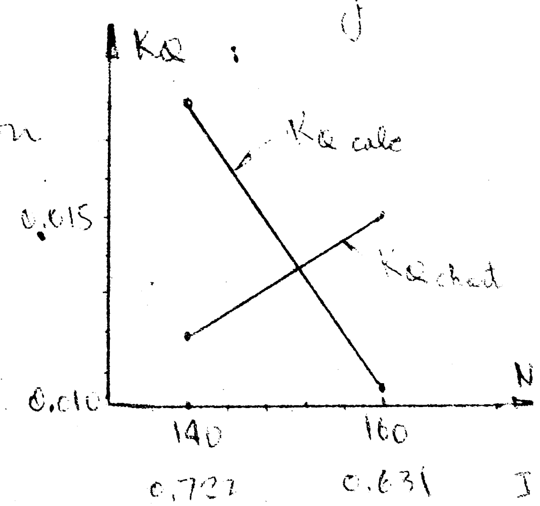
for n = 140 $K_{Q\,calc.} > K_{Q\,chart}$, while for n = 160 $K_{Q\,calc} < K_{Q\,chart}$.

The equilibrium RPM is obviously between 140 and 160.

By graphical interpolation we can find

$N_{eq} = 156$ rpm

$J_{eq} = 0.652$



From J_{eq} and P/D we finally find $\eta_0 = 69.0\%$, from the chart.

TABLE 78 SAMPLE CALCULATION (CONT'D)

The propeller efficiency of all propellers is found similarly, and then the combined open water efficiency of the whole arrangement is found by:

$$\eta_{o\,TOTAL} = \frac{1}{\sum \frac{SHP_i}{SHP_{total}} \cdot \frac{1}{\eta_{oi}}}$$

Results are summarized in tables 30 for average diameters and in tables for limit diameters

For the twin screw, as both propellers have equal efficiencies, the combined efficiency is equal to the efficiency of each propeller.

2. Calculation of Hull Efficiency

$$\eta_{Hi} = \frac{1-t_i}{1-w_i}$$

Using the values of t_i, w_i as assumed in table 77, we get

$$\eta_{H\,c.s} = \frac{1-t_{cs}}{1-w_{cs}} = \frac{1-0.15}{1-0.25} = \frac{0.85}{0.75} = \frac{1}{0.9117}$$

$$\eta_{H\,o.s} = 1 \text{ , as } t_{o.s} = w_{o.s}$$

TABLE 79 SAMPLE CALCULATION (CONT'D)

Now we can calculate the total hull efficiency for the different arrangements, using:

$$\eta_{H\,total} = \frac{1}{\sum \frac{SHP_i}{SHP_{TOTAL}} \cdot \frac{1}{\eta_{Hi}}}$$

a) For twin screw

$$\eta_{H\,total} = \eta_{H_i} = 1$$

b) For triple screw 1:1:1

$$\eta_{H\,total} = \frac{1}{\underbrace{\frac{1}{3} \cdot 0.9117}_{0.5} + 2 \cdot \underbrace{\frac{1}{3} \cdot 1}_{0.5}} = 1.030$$

c) For triple screw 1:2:1

$$\eta_{H\,total} = \frac{1}{\frac{1}{2} \cdot 0.9117 + 2 \cdot \frac{1}{4} \cdot 1} = 1.046$$

3. Total Propulsive Efficiency

$$\eta_P = \eta_0 \cdot \eta_H \, \eta_R$$

Assuming η_R, the relative efficiency to be unity for all cases, we get the total propulsive efficiency as:

$$\eta_{P\,TOTAL} = \eta_{o\,TOTAL} \cdot \eta_{H\,TOTAL}$$

using the corresponding precalculated η_{ot}, η_{Ht}.

TABLE 80 EFFICIENCY AT 18 KNOTS

CASE I SHP$_{TOTAL}$ = 15,000 OUT

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW (1:1:1)						TRIPLE SCREW (1:2:1)					
PROP. TYPE	SHP FREE-RUN.	N RPM	η_p TOTAL	RPM C.S	RPM O.S	η_o C.S.	η_o O.S	η_o TOTAL	η_p TOTAL	RPM C.S	RPM O.S	η_o C.S	η_o O.S	η_o TOTAL	η_p TOTAL
B-3.50	6,000	138	66.0	136	126	74.5	73.5	73.8	76.0	142	123	60.0	74.2	66.5	69.5
	9,000	148	69.0	145	137	74.8	70.5	71.9	74.0	152	134	65.0	69.1	66.7	69.7
	12,000	156	69.0	154	146	71.5	68.0	69.1	71.2	159	143	65.5	67.5	66.7	69.7
	15,000	162	67.5	160	153	70.1	65.0	66.6	68.6	167	152	66.0	65.0	65.6	68.6
B-3.65	6,000	151	55.0	145	135	70.4	70.5	70.5	72.6	152	132	45.0	74.0	56.1	58.7
	9,000	157	61.0	155	146	70.5	68.0	68.8	70.8	159	141	52.5	70.2	60.1	62.9
	12,000	165	60.4	163	154	69.4	66.0	67.1	69.1	167	152	55.0	66.5	60.2	63.0
	15,000	172	60.2	170	160	67.5	63.5	64.8	66.8	174	159	56.0	65.0	60.2	63.0
B-4.55	6,000	139	50.0	135	125	69.3	70.5	70.1	72.3	146	121	46.0	74.5	56.1	58.7
	9,000	149	57.5	144	136	70.4	69.6	69.8	71.9	154	132	50.0	69.5	58.2	60.9
	12,000	157	60.0	153	144	70.5	67.5	68.5	70.6	159	140	53.5	66.0	59.1	61.9
	15,000	163	61.0	159	152	69.0	65.2	66.4	68.4	167	149	55.1	66.0	60.1	62.9
B-4.70	6,000	142	50.0	141	132	67.2	69.0	68.5	70.6	147	132	35.0	71.0	46.9	49.0
	9,000	153	57.5	152	140	69.0	68.0	68.3	70.4	156	141	50.0	69.2	58.1	60.8
	12,000	161	60.0	160	150	69.0	66.5	67.3	69.3	164	151	55.0	67.0	60.5	63.3
	15,000	168	60.5	167	157	67.8	64.9	65.8	67.7	171	158	56.5	65.0	60.5	63.3
Diameter		16.25'		13.50'						16.88 / 11.81					

Notation:

C.S. = center screw ; O.S = outboard screw

η_o = propeller efficiency - in open water

η_p = propulsive efficiency = $\eta_o * \eta_h \cdot \eta_r$

L = too low free running SHP for the propeller.

H = too high total SHP for the propeller (P/D out of range)

TABLE 81 PROPULSIVE EFFICIENCY AT 18 KNOTS

CASE I $SHP_{TOTAL} = 30,000$ OUT

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW (1:1:1)						TRIPLE SCREW (1:2:1)					
DIA., FT		16.25		13.50						16.88 / 11.81					
PROP SIZE	SHP FREE RUNNING	RPM	η_p %	RPM C.S.	RPM O.S.	η_o % C.S.	η_o % O.S.	η_o TOTAL %	η_p TOTAL %	RPM C.S.	RPM O.S.	η_o % C.S.	η_o % O.S.	η_o TOTAL %	η_p TOTAL %
B-3.50	12000	129	68.3	H	H	–	–	–	–	×	H	×	–	–	–
	15000	135	66.6	H	H	–	–	–	–	×	H	×	–	–	–
	18000	139	64.9	H	H	–	–	–	–	×	H	×	–	–	–
	21000	142	63.7	H	H	–	–	–	–	×	H	×	–	–	–
B-3.65	9000	121	72.5	L	L	–	–	–	–	×	H	×	–	–	–
	12000	129	70.3	122	L	71.3	–	–	–	×	H	×	–	–	–
	15000	134	68.3	127	123	69.5	62.5	64.7	66.7	×	H	×	–	–	–
	18000	138	66.5	131	129	67.0	60.0	64.1	66.0	×	H	×	–	–	–
	21000	141	65.9	135	134	65.9	59.4	61.5	63.4	×	H	×	–	–	–
B-4.55	15000	124	70.0	H	H	–	–	–	–	×	H	×	–	–	–
	18000	130	66.6	H	H	–	–	–	–	×	H	×	–	–	–
	21000	135	66.3	H	H	–	–	–	–	×	H	×	–	–	–
	24000	138	65.2	H	H	–	–	–	–	×	H	×	–	–	–
B-4.70	12000	125	70.0	126	L	70.9	–	–	–	×	H	×	–	–	–
	15000	131	67.8	132	125	68.7	64.1	65.6	67.6	×	H	×	–	–	–
	18000	136	66.6	137	131	66.3	61.7	63.2	65.1	×	H	×	–	–	–
	21000	140	65.7	141	136	65.3	59.8	62.2	64.1	×	H	×	–	–	–

L - LOW FREE RUNNING SHP

H - P/G HIGHER THAN 140

TABLE 82 PROPULSIVE EFFICIENCY AT 18 KNOTS

CASE I $SHP_{TOTAL} = 45,000$

OUT

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW (1:1:1)						TRIPLE SCREW (1:2:1)					
PROP. DIA.		16.25'		13.50'						16.88' / 11.81'					
TYPE	SHP FREE RUNNING	RPM	η_P [%]	RPM C.S	RPM 0.5	η_0 [%] C.S	η_0 [%] 0.5	η_0 TOTAL [%]	η_P TOTAL [%]	RPM C.S	RPM 0.5	η_0 [%] C.S.	η_0 [%] 0.5	η_0 TOTAL [%]	η_P TOTAL [%]
B-3.50		H	—	H	H	—	—	—	—	x	H	x	—	—	—
		H	—	H	H	—	—	—	—	x	H	x	—	—	—
		H	—	H	H	—	—	—	—	x	H	x	—	—	—
		H	—	H	H	—	—	—	—	x	H	x	—	—	—
B-3.65	21,000	121	64.5	H	H	—	—	—	—	x	H	x	—	—	—
	24,000	126	62.5	H	H	—	—	—	—	x	H	x	—	—	—
	27,000	130	61.0	H	H	—	—	—	—	x	H	x	—	—	—
	30,000	133	59.5	H	H	—	—	—	—	x	H	x	—	—	—
B-4.55		H	—	H	H	—	—	—	—	x	H	x	—	—	—
		H	—	H	H	—	—	—	—	x	H	x	—	—	—
		H	—	H	H	—	—	—	—	x	H	x	—	—	—
		H	—	H	H	—	—	—	—	x	H	x	—	—	—
B-4.70	21,000	123	65.0	H	H	—	—	—	—	x	H	x	—	—	—
	24,000	127	63.0	H	H	—	—	—	—	x	H	x	—	—	—
	27,300	131	62.4	H	H	—	—	—	—	x	H	x	—	—	—
	30,000	134	61.5	H	H	—	—	—	—	x	H	x	—	—	—

x = not calculated, as the other screws in the arrangement are out of the range of Wageningen screws.

H - P/D HIGHER THAN 1.40

TABLE 83

CASE II

18 KNOTS PROPULSIVE EFFICIENCY

$SHP_{TOTAL} = 30,000$

OUT

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW (1:1:1)						TRIPLE SCREW (1:2:1)					
PROP. TYPE	SHP FREE RUNNING	RPM	η_p TOTAL [%]	RPM		η_o [%]		η_o TOTAL [%]	η_p TOTAL [%]	RPM		η_o %		η_o TOTAL %	η_p TOTAL %
				C.S	O.S	C.S	O.S			C.S	O.S	C.S	O.S		
B-3.50	9000	121	67.5	120	L	75.0	—	—	—	125	L	65.0	—	—	—
	12,000	128	68.3	127	L	73.2	—	—	—	131	L	66.0	—	—	—
	15,000	133	69.0	132	126	71.7	67.5	68.9	71.0	136	125	66.7	66.5	66.6	69.7
	18,000	138	68.0	137	132	70.0	65.0	68.6	70.7	141	129	66.8	65.5	66.1	69.1
	21000	142	67.0	143	136	66.2	64.0	65.4	67.4	148	133	65.8	64.0	64.9	67.8
B-3.65	9000	131	58.0	127	L	71.0	—	—	—	132	L	52.5	—	—	—
	12,000	136	60.0	133	125	70.8	68.0	69.0	71.1	137	124	55.0	70.2	61.6	64.4
	15000	140	60.8	138	132	70.0	66.0	67.3	69.3	140	131	55.0	67.5	60.6	63.4
	18000	146	61.0	142	136	69.0	65.0	66.4	68.4	145	136	57.2	65.7	61.2	64.0
	21000	150	61.0	147	139	67.5	63.0	64.5	66.4	151	139	57.5	65.0	61.1	63.9
B-4.55	9000	124	54.5	L	L	—	—	—	—	126	L	45.0	—	—	—
	12000	130	57.8	125	L	70.6	—	—	—	132	L	53.0	—	—	—
	15000	135	60.2	130	123	70.5	68.0	68.8	70.9	136	120	55.8	69.0	61.8	64.6
	18000	139	60.7	135	129	70.0	65.5	67.0	69.0	141	128	57.0	66.2	61.3	64.1
	21000	145	61.3	139	134	68.8	64.2	65.7	67.7	147	131	58.2	65.0	61.5	64.3
B-4.70	9000	129	56.0	126	L		—	—	—	129	L	44.0	—	—	—
	12000	134	58.5	132	121	69.0	68.0	68.5	70.6	135	123	53.2	70.0	60.3	63.0
	15000	139	60.2	136	129	69.0	66.4	67.2	69.3	139	130	55.0	67.0	60.5	63.2
	18000	144	61.8	142	134	68.0	65.0	66.1	68.1	144	135	57.0	65.5	61.0	63.8
	21,000	148	61.2	146	138	67.0	64.4	65.3	67.3	149	138	57.0	64.0	60.4	63.1
DIAMETER		18.56'		15.46'						19.2' / 13.6'					

L : LOW F.R. SHP

H : P/D HIGHER THAN 1.40

TABLE 84 — CASE II

18 KNOTS PROPULSIVE EFFICIENCY

$SHP_{TOTAL} = 45,000$ OUT

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW (1:1:1)						TRIPLE SCREW (1:2:1)					
DIAMETER		18.56'		15.46'						19.2' / 13.6'					
PROP TYPE	SHP F.R	RPM	η_p %	RPM C.S	RPM O.S	η_o % C.S	η_o % O.S	η_o TOTAL %	η_p TOTAL %	RPM C.S.	RPM O.S	η_o % C.S	η_o % O.S	η_o TOTAL %	η_p TOTAL %
B-3.50	21000	123	69.2	X	L	X	—	—	—	X	H	X	—	—	—
	24000	127	67.8	X	L	X	—	—	—	X	H	X	—	—	—
	27000	131	65.5	128	123	65.8	60.2	62.1	[illegible]	X	H	X	—	—	—
	30000	134	65.0	132	126	64.0	59.0	60.6	62.5	X	H	X	—	—	—
	33000	136	64.2	134	130	64.0	58.0	59.9	61.6	X	H	X	—	—	—
B-3.65	18000	127	65.6	X	L	X	—	—	—	X	H	X	—	—	—
	21000	131	65.6	129	121	63.5	63.0	64.8	66.7	X	H	X	—	—	—
	24000	134	65.6	132	126	67.0	61.2	[illegible]	64.1	X	H	X	—	—	—
	27000	137	64.0	136	128	65.2	60.0	61.6	63.5	X	H	X	—	—	—
	30000	140	63.5	138	132	64.4	57.6	59.7	61.5	X	H	X	—	—	—
B-4.55	21000	123	67.5	L	L	—	—	—	—	X	H	X	—	—	—
	24000	127	66.0	X	L	X	—	—	—	X	H	X	—	—	—
	27000	130	65.6	125	120	67.5	62.0	63.7	66.6	X	H	X	—	—	—
	30000	133	65.0	129	124	65.8	60.0	61.9	63.7	X	H	X	—	—	—
	3300	136	64.0	132	128	65.0	59.0	60.8	62.6	X	H	X	—	—	—
B-4.70	18000	122	67.0	X	L	X	—	—	—	X	L	X	—	—	—
	21000	127	66.8	X	L	X	—	—	—	130	121	65.8	63.2	64.5	67.5
	24000	131	65.8	131	124	67.0	62.0	63.6	65.5	133	128	65.4	60.4	62.8	65.0
	27000	134	65.2	134	128	65.8	61.0	62.5	64.4	136	129	64.4	60.0	62.4	65.2
	30000	137	64.5	137	131	64.6	59.2	61.0	62.9	139	133	64.2	58.4	61.1	63.0

L TOO LOW F.R. SHP

H P/D HIGHER THAN 1.40

TABLE 85 — 18 KNOTS PROPULSIVE EFFICIENCY

CASE II — $SHP_{TOTAL} = 60,000$ — OUT

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW (1:1:1)						TRIPLE SCREW (1:2:1)					
DIA., FT		18.56'		15.46						19.20'/13.60'					
PROP SIZE	SHP FREE RUNNING	RPM	η_p %	RPM C.S	RPM O.S	η_o % C.S	η_o % O.S	η_o TOTAL %	η_p TOTAL %	RPM C.S.	RPM O.S	η_o % C.S	η_o % O.S	η_o TOTAL %	η_p TOTAL %
B-3.50	30000	121	64.4	H	H	–	–	–	–	X	H	X	–	–	–
	33000	124	63.2	H	H	–	–	–	–	X	H	X	–	–	–
	36000	127	61.7	H	H	–	–	–	–	X	H	X	–	–	–
	39000	130	60.9	H	H	–	–	–	–	X	H	X	–	–	–
B-3.65	30000	128	63.5	124	L	62.5	–	–	–	X	H	X	–	–	–
	33000	131	62.0	126	121	62.0	55.8	58.7	60.5	X	H	X	–	–	–
	36000	133	61.9	129	123	61.0	55.6	57.4	59.1	X	H	X	–	–	–
	39000	136	60.8	132	126	60.0	54.4	56.3	58.0	X	H	X	–	–	–
B-4.55	30000	L	–	H	H	–	–	–	–	X	H	X	–	–	–
	33000	121	64.8	H	H	–	–	–	–	X	H	X	–	–	–
	36000	124	63.6	H	H	–	–	–	–	X	H	X	–	–	–
	39000	127	62.6	H	H	–	–	–	–	X	H	X	–	–	–
B-4.70	30000	125	64.2	120	L	63.6	–	–	–	X	H	X	–	–	–
	33000	128	63.5	128	122	63.0	58.0	59.6	61.4	X	H	X	–	–	–
	36000	130	62.5	130	124	62.2	57.5	59.0	60.8	X	H	X	–	–	–
	39000	133	61.6	133	128	61.2	55.2	57.0	58.7	X	H	X	–	–	–

L : TOO LOW FREE RUNNING SHP

H : P/D RATIO OVER 1.40

TABLE 86 — 18 KNOTS PROPULSIVE EFFICIENCY

CASE III — $SHP_{TOTAL} = 30000$ OUT

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW (1:1:1)						TRIPLE SCREW (1:2:1)					
DIA., FT		20.88		17.40						21.62 / 15.29					
PROP. SIZE	SHP FREE RUNNING	RPM	η_p %	RPM C.S	RPM O.S	η_o % C.S	η_o % O.S	η_o TOTAL %	η_p TOTAL %	RPM C.S	RPM O.S	η_o % C.S	η_o % O.S	η_o TOTAL %	η_p TOTAL %
B-3.50	6000	127	<30.0	X	L	X	—	—	—	X	L	X	—	—	—
	9000	133	<30.0	X	L	X	—	—	—	X	L	X	—	—	—
	12000	138	41.0	134	125	66.8	68.0	67.6	69.6	138	123	<30	X	X	<40
	15000	144	53.0	138	131	67.5	67.0	67.2	69.2	145	129	<30	X	X	<40
B-3.65	6000	129	<30.0	133	120	40.0	50.4	46.6	48.0	X	L	X	—	—	
	9000	136	<30.0	139	128	50.0	55.0	53.2	54.8	138	127	<30.0	X	X	<40
	12000	140	<30	145	134	55.0	58.0	57.0	58.7	143	133	<30	X	X	<40
	15000	145	40.0	150	139	57.5	68.6	64.4	66.3	150	137	<30	X	X	<40
B-4.55	6000	126	<30.0	X	L	X	—	—	—	X	L	X	—	—	—
	9000	132	<30.0	X	L	X	—	—	—	X	L	X	—	—	—
	12000	137	32.0	136	125	50.0	57.0	54.5	56.1	143	126	<30	X	X	<40
	15000	142	40.0	134	131	52.0	58.6	56.2	57.9	150	131	<30	X	X	<40
B-4.70	6000	128	<30.0	X	L	X	—	—	—	X	L	X	—	—	—
	9000	135	<30.0	134	124	40.0	55.4	49.1	50.6	137	124	<30.0	X	X	<40
	12000	139	<30	140	131	54.0	58.2	57.1	58.8	142	131	<30	X	X	<40
	15000	144	<30	145	136	55.8	60.8	59.0	60.8	148	135	<30	X	X	<40

L : TOO LOW FREE RUNNING SHP

TABLE 87 18 KNOTS PROPULSIVE EFFICIENCY

CASE III SHP$_{TOTAL}$ = 45,000 OUT

ARRANGEMENT		TWIN-SCREW		TRIPLE SCREW (1:1:1)						TRIPLE SCREW (1:2:1)					
DIA., FT		20.88		17.40						21.62 / 16.29					
PROP. SIZE	SHP FREE RUNNING	RPM	η_p %	RPM C.S.	RPM O.S.	η_o % C.S.	η_o % O.S.	η_o TOTAL %	η_p TOTAL %	RPM C.S	RPM O.S	η_o % C.S	η_o % O.S	η_o TOTAL %	η_p TOTAL %
B-3.50	21000	129	65.8	128	121	70.6	67.0	68.0	70.1	133	L	62.5	—	—	—
	24000	133	66.4	132	125	69.8	65.5	66.9	68.9	137	124	63.0	[illegible]	64.0	66.9
	27000	136	65.8	135	129	69.0	64.0	65.6	67.6	139	128	63.2	63.4	63.3	66.2
	30000	138	65.6	137	133	68.6	63.0	64.9	66.8	143	131	[illegible]	63.0	63.2	66.1
B-3.65	21000	136	57.5	136	128	66.5	63.6	64.6	66.5	135	127	53.0	[illegible]	58.9	[illegible]
	24000	139	57.2	139	132	66.4	62.5	63.7	65.6	139	131	53.7	[illegible]	58.8	61.5
	27000	142	57.0	142	135	65.6	62.0	63.1	65.0	140	135	54.3	63.4	58.9	61.6
	30000	144	57.0	145	137	65.0	60.6	62.1	64.0	144	132	55.0	62.0	58.4	61.0
B-4.55	21000	131	55.5	129	121	67.0	65.8	66.3	68.3	131	L	56.8	—	—	—
	24000	135	57.0	133	125	67.2	64.8	65.6	67.6	135	122	51.7	66.4	58.2	60.9
	27000	137	58.0	135	129	67.2	63.6	64.9	66.8	137	126	52.8	65.0	58.3	61.0
	30000	140	58.0	138	132	66.5	62.0	63.5	65.4	140	129	53.7	64.0	58.4	61.0
B-4.70	21000	134	55.0	133	125	66.8	65.5	66.0	68.0	134	125	50.0	66.2	57.0	59.6
	24000	137	57.0	136	129	66.4	64.0	64.8	66.7	138	129	52.5	65.0	58.1	60.8
	27000	140	57.0	139	133	66.0	62.5	63.6	65.5	139	133	53.0	63.6	57.9	60.5
	30000	141	56.0	142	135	65.6	61.8	63.0	64.9	145	136	53.0	62.6	57.4	60.0

L : TOO LOW FREE RUNNING SHP FOR THE PROPELLER

TABLE 88. 18 KNOTS PROPULSIVE EFFICIENCY

CASE III SHP$_{TOTAL}$ = 60,000 OUT

ARRANGEMENT		TWIN SCREW		TRIPLE SCREW (1:1:1)						TRIPLE SCREW (1:2:1)					
DIA., FT		20.88		17.40						21.62 / 16.20					
PROP. SIZE	SHP FREE RUNNING	RPM	η_p %	RPM C.S.	RPM O.S	η_o % C.S.	η_o % O.S.	η_o TOTAL %	η_p TOTAL %	RPM C.S.	RPM O.S.	η_o % C.S.	η_o % O.S.	η_o TOTAL %	η_p TOTAL %
B-3.50	27 000	121	68.0	121	L	69.6	—	—	—	125	L	66.6	—	—	—
	30 000	125	67.2	124	L	68.0	—	—	—	128	L	65.6	—	—	—
	33 000	128	65.8	128	121	66.0	61.4	62.8	64.6	130	121	65.4	63.5	62.9	65.8
	36,000	130	65.0	130	124	65.4	60.0	61.7	63.5	133	124	65.0	58.2	61.5	64.4
B-3.65	27000	130	62.0	128	120	67.0	63.6	64.8	66.7	131	L	60.0	—	—	—
	30000	133	61.5	131	124	66.0	61.6	63.0	64.9	133	122	60.0	62.5	61.2	64.0
	33000	136	60.6	134	127	65.6	61.0	62.5	64.4	135	126	59.8	60.0	59.9	62.6
	36000	138	60.6	135	130	65.0	60.0	61.6	63.5	138	128	59.6	59.0	59.3	62.0
B-4.55	27000	123	63.8	L	L	—	—	—	—	124	L	60.0	—	—	—
	30000	126	63.6	123	L	68.0	—	—	—	127	L	60.4	—	—	—
	33000	129	63.2	126	L	67.0	—	—	—	130	L	61.0	—	—	—
	36000	131	62.5	128	122	65.8	62.0	63.3	65.2	133	L	60.8	—	—	—
B-4.70	27000	128	63.0	126	L	67.5	—	—	—	124	L	60.0	—	—	—
	30000	131	63.0	129	122	66.4	62.5	[illegible]	65.6	132	122	60.5	63.0	61.7	64.6
	33000	133	62.2	132	125	65.6	61.0	62.5	64.4	134	126	60.4	60.8	60.6	63.4
	36000	136	62.0	134	127	65.0	61.0	62.3	64.2	137	128	60.6	60.4	60.2	63.0

L : TOO LOW FREE RUNNING SHP FOR THE PROPELLER

APPENDIX II: FIGURES.

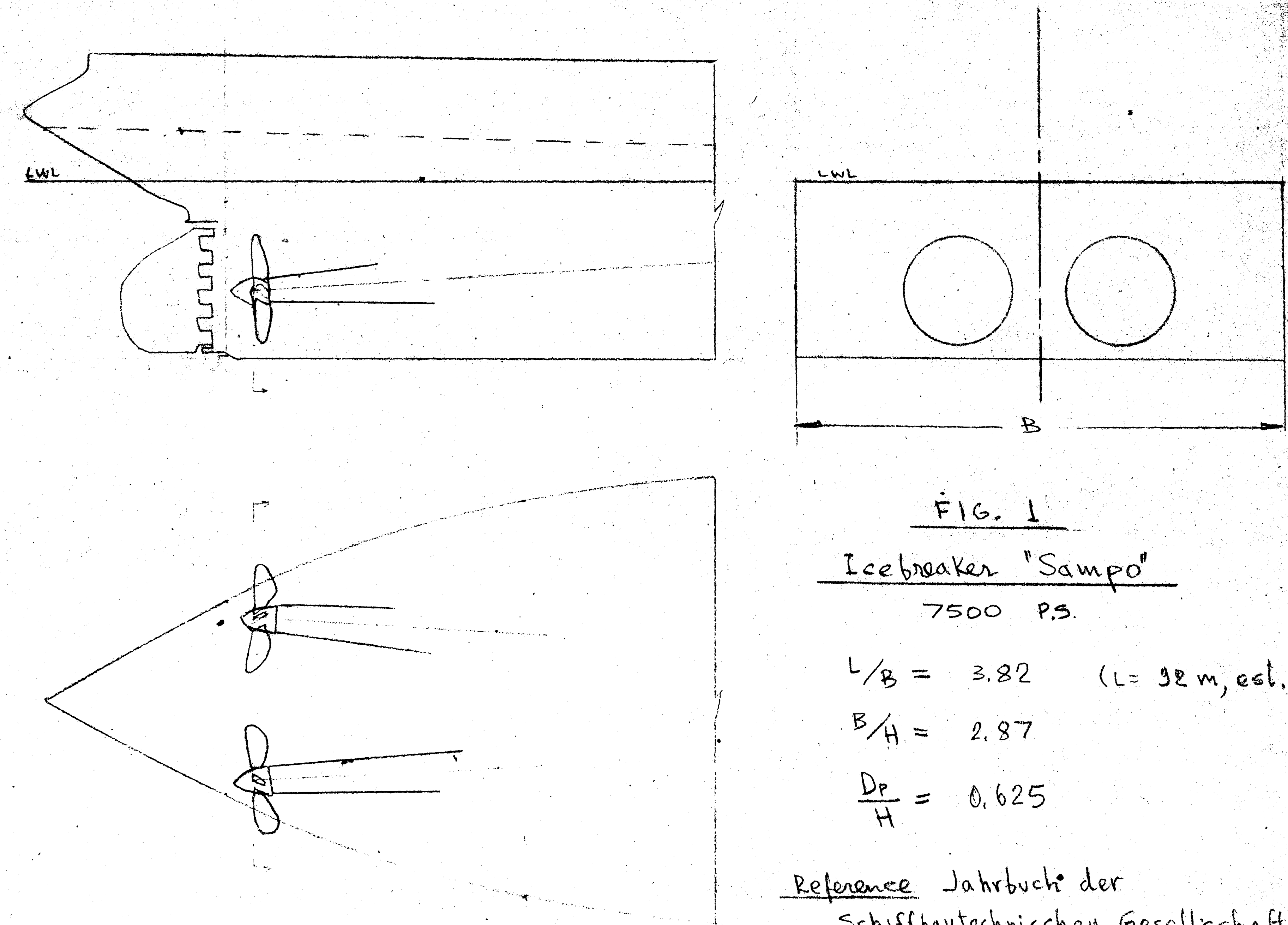


FIG. 1

Icebreaker "Sampo"

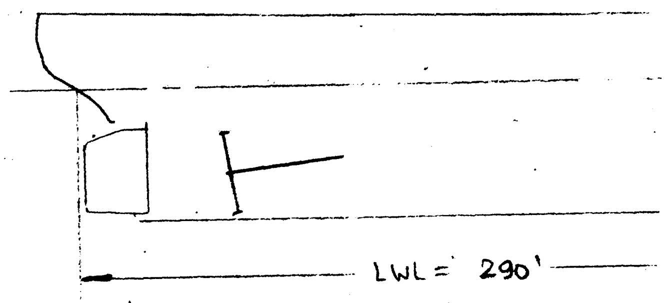
7500 P.S.

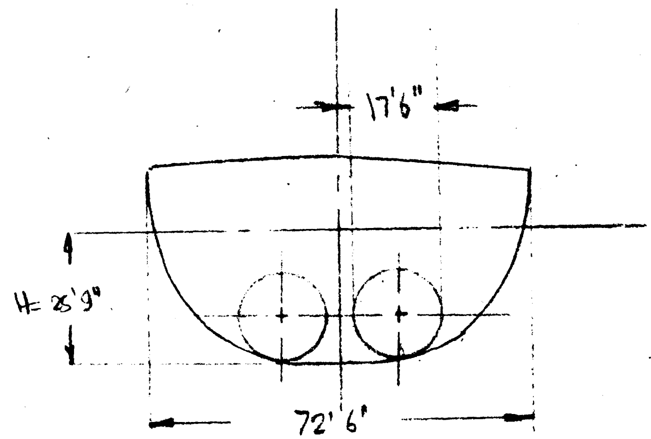
$L/B = 3.82$ (L = 92 m, est.)

$B/H = 2.87$

$\frac{D_P}{H} = 0.625$

Reference Jahrbuch der Schiffbautechnischen Gesellschaft, 1962 (P. 145)





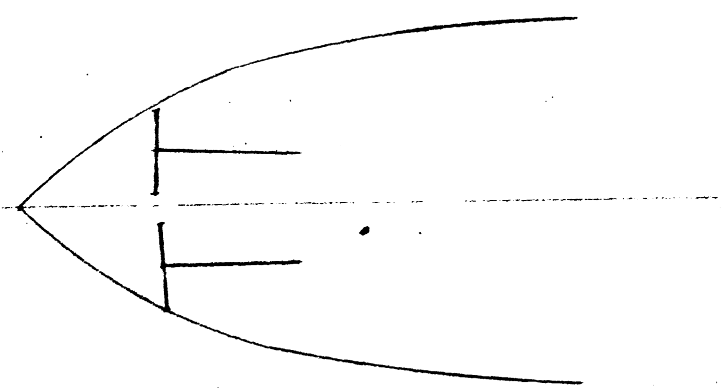
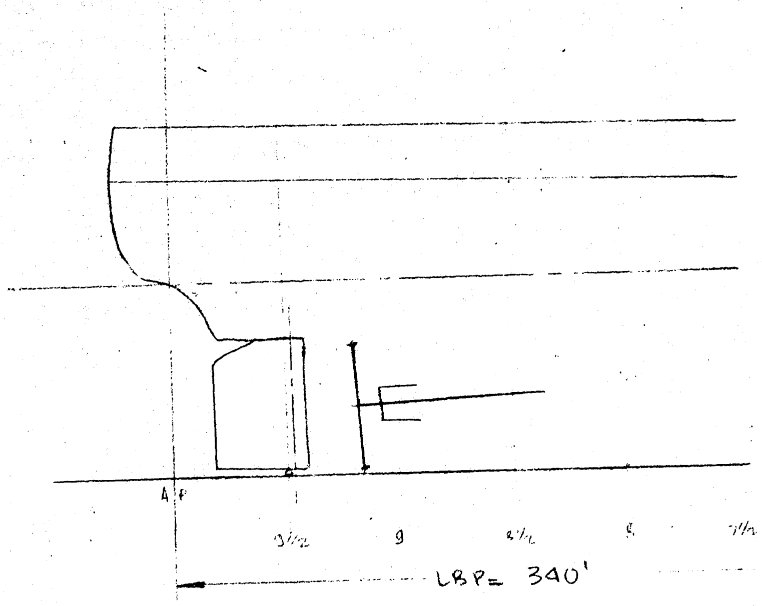
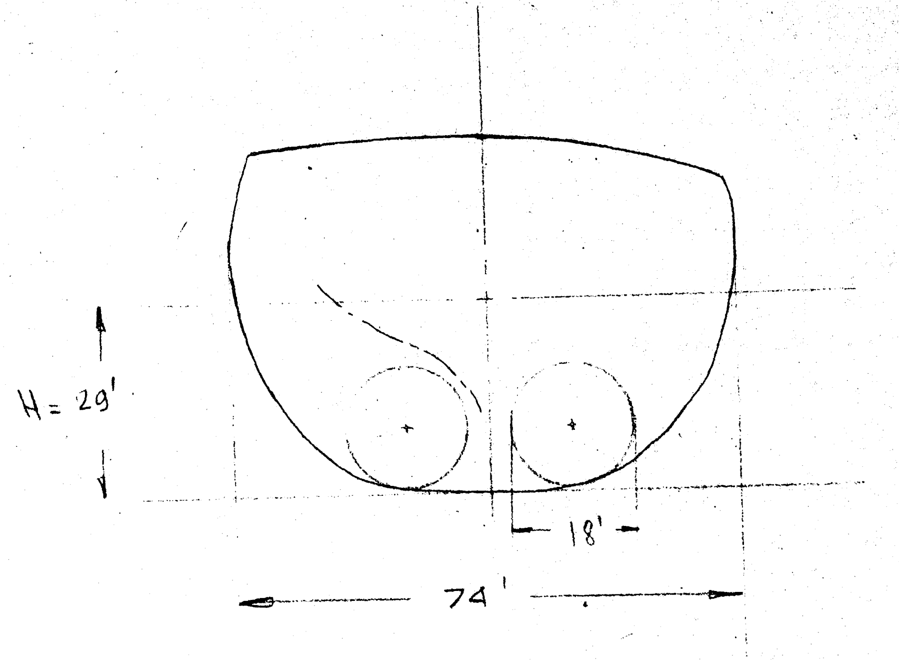


Fig. 2 Icebreaker USS Glacier

(Ref SNAME Trans. 1959)

L/B	:	4.00
B/H	:	2.82
Dp/H	:	0.68
Displacement	:	8640 L.T.
SHP_{max}	:	21,000
speed	:	16 knts





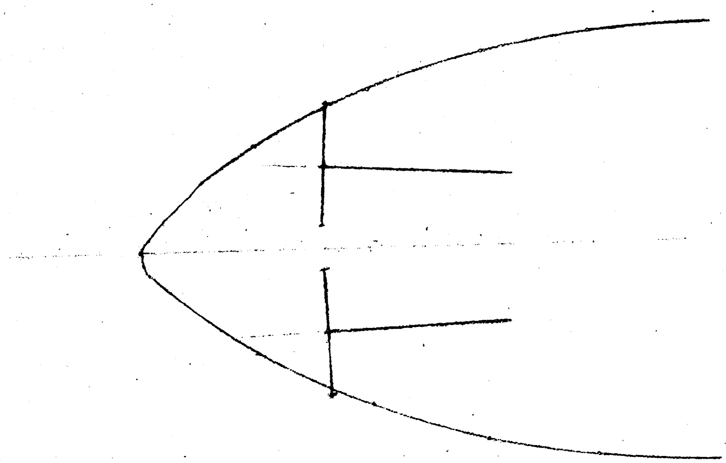


Fig 3 **Nuclear Icebreaker**

(Lonk & Oakley Design, SNAME 1959)

L/B = 4.60

B/H = 2.55

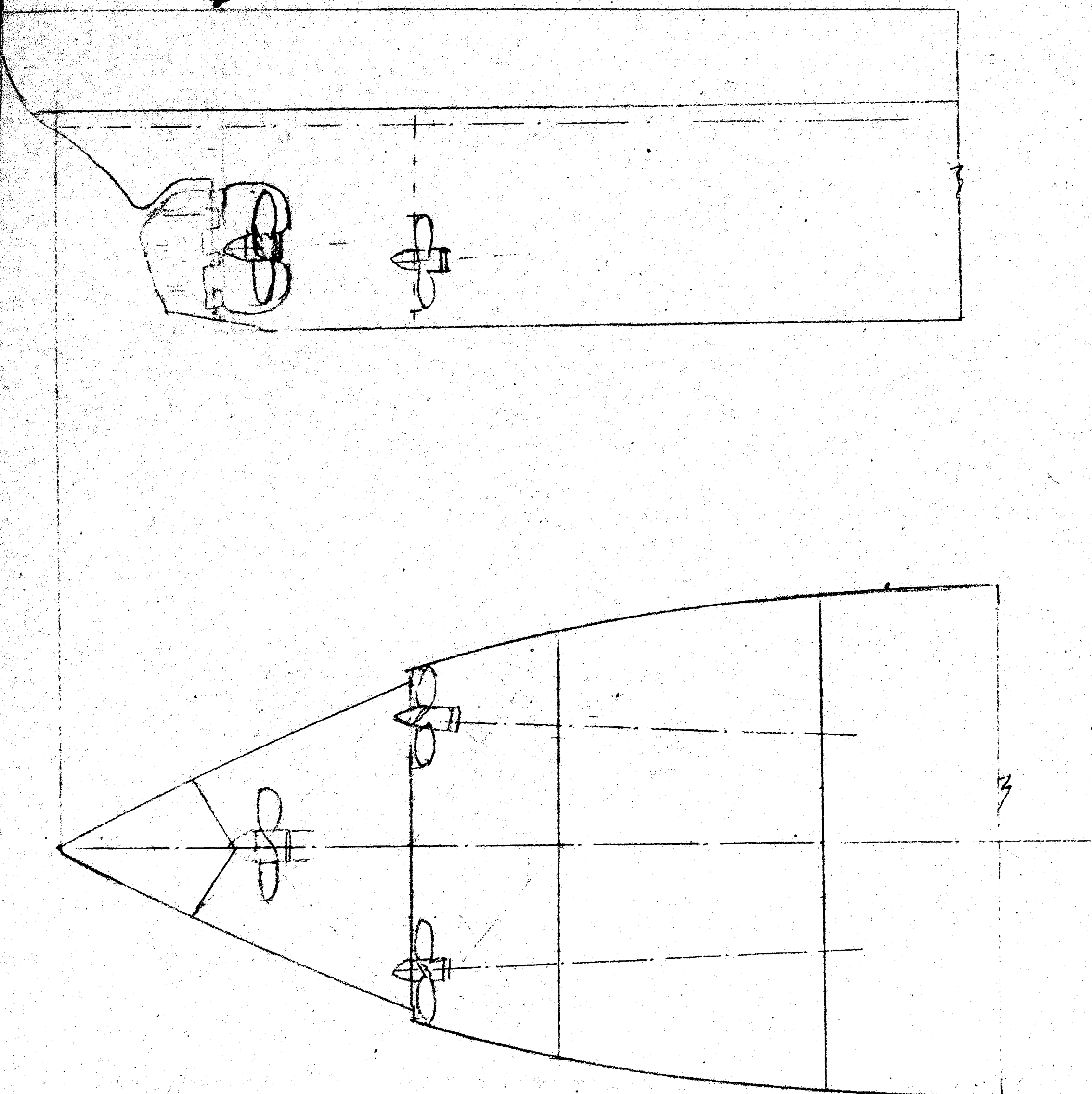
D_P/H = 0.621

Displacement : 10,300 L.T.

SHP_{max} : 30,000

$speed_{max}$ 18 kts

FIG. 4



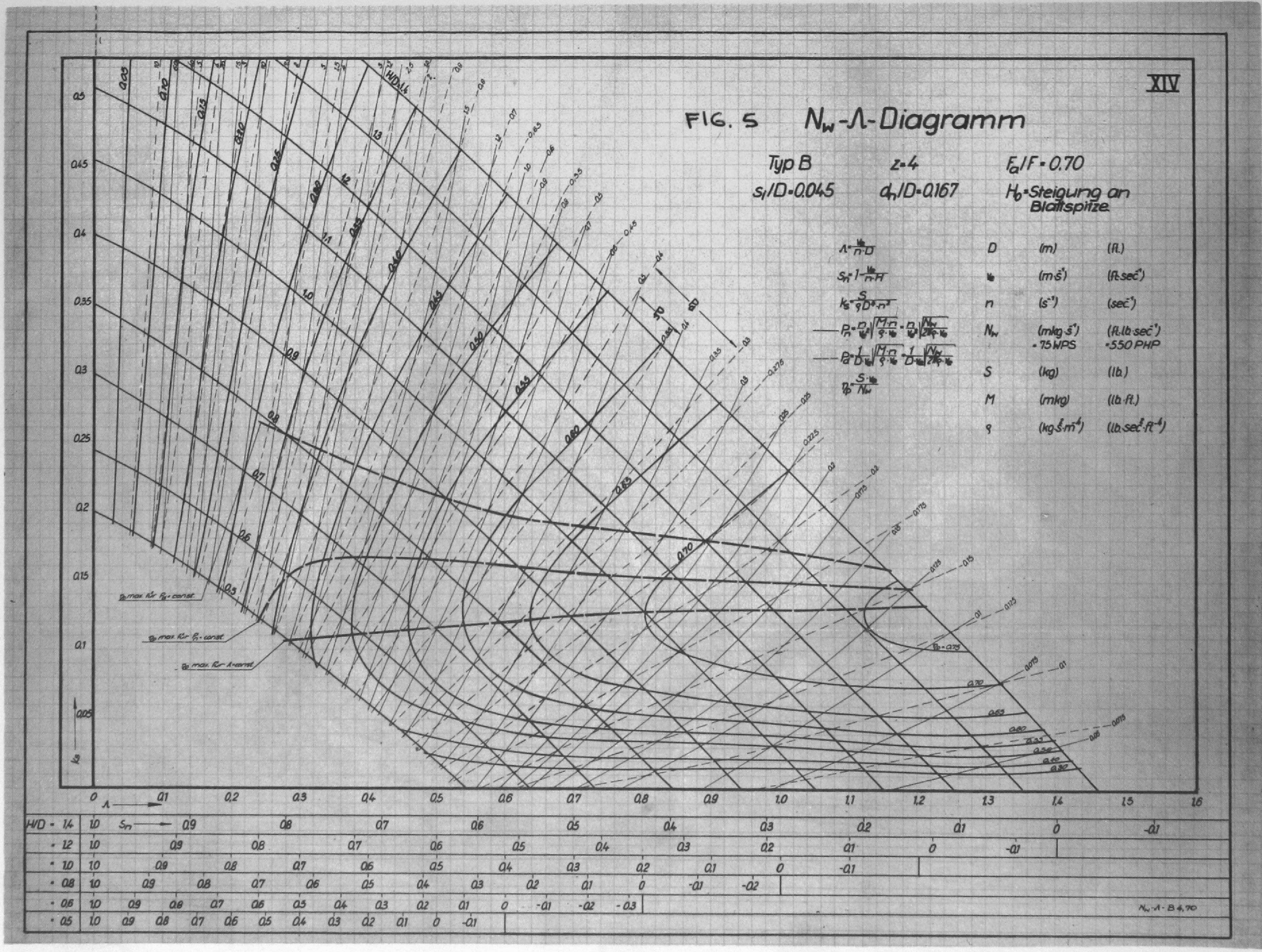
SKETCH SHOWS THE GENERAL ARRGT OF TRIPLE SCREWS BASED ON THE "MOSCOW CLASS" ICE BREAKERS (U.S.S.R.)

DIMENSIONS:

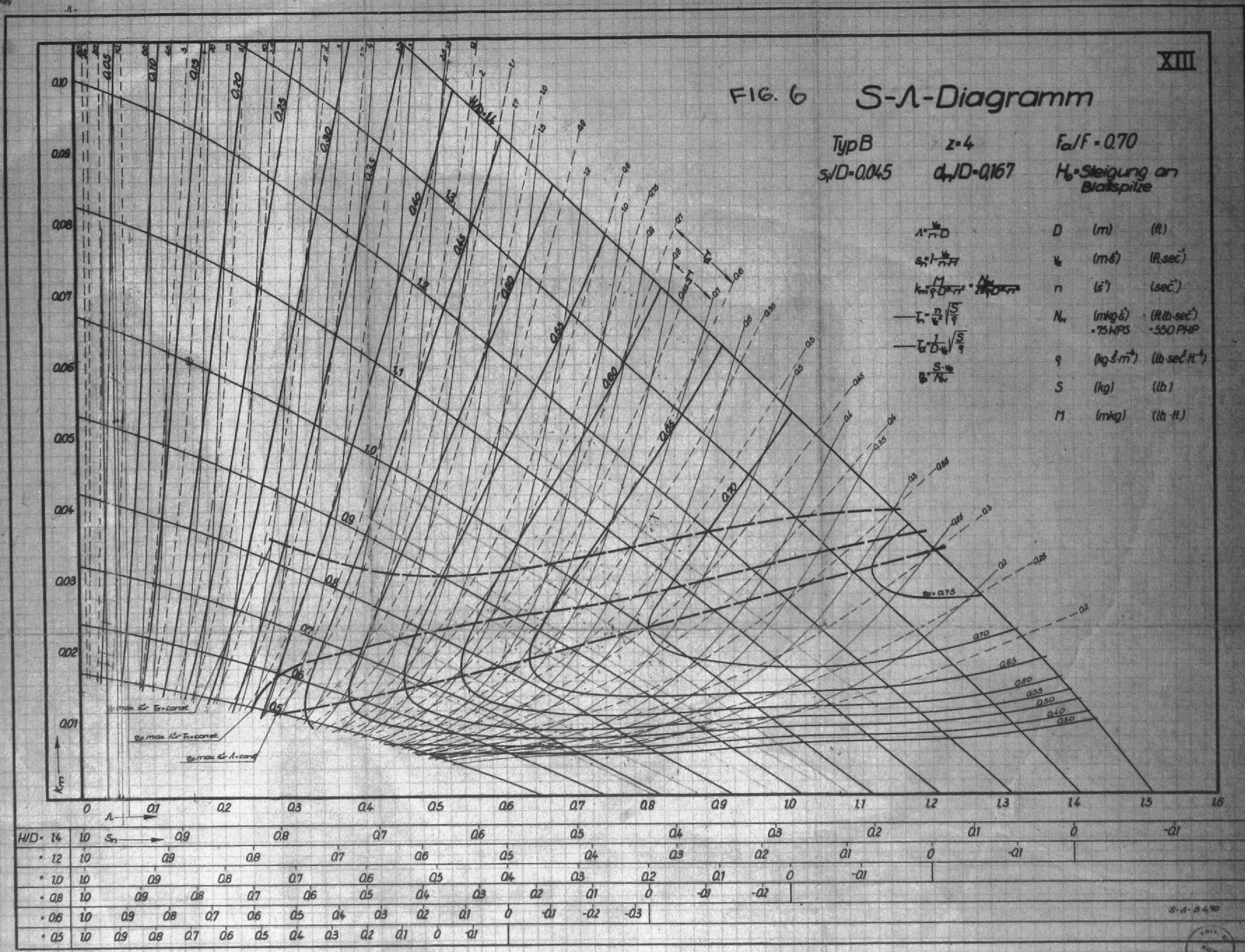
LENGTH O.A.	400' 7"
BEAM, max.	80'-4½"
DRAFT, max.	34'-5½"
DISPLACEMENT, max	15,360 tons (metric)
SHP, max	22,000
SPEED, max	18 kts

REFERENCE:

WÄRTSILÄ - KONCERNEN A/B SANDVIKENS SKEPPSDOCKA



XIV
FIG. 5 Nw-Λ-Diagramm
Typ B
z=4
Fa/F=0.70
s1/D=0.045
dn/D=0.167
Ho=Steigung an Blattspitze
D (m) (ft.)
(m·s⁻¹) (ft·sec⁻¹)
n (s⁻¹) (sec⁻¹)
Nw (mkg·s⁻¹) =75 WPS (ft.lb·sec⁻¹) =550 PHP
S (kg) (lb.)
M (mkg) (lb.ft.)
ρ (kg·s²·m⁻⁴) (lb.sec²·ft⁻⁴)
ηp max für Pa=const.
ηp max für Pn=const.
ηp max für Λ=const.
H/D = 1.4
Sn
Λ
Nw-Λ-B 4,70


XIII
FIG. 6 S-Λ-Diagramm
Typ B
$s_1/D = 0.045$
z = 4
$d_n/D = 0.167$
$F_a/F = 0.70$
H_0 = Steigung an Blattspitze
D (m) (ft.)
(m s⁻¹) (ft. sec⁻¹)
n (s⁻¹) (sec⁻¹)
(mkg s⁻¹) = 75 WPS (ft.lb. sec⁻¹) = 550 PHP
ϱ (kg s² m⁻⁴) (lb. sec² ft⁻⁴)
S (kg) (lb.)
M (mkg) (lb. ft.)
k_m
Λ
s_n
H/D = 1.4
= 1.2
= 1.0
= 0.8
= 0.6
= 0.5
S-Λ-B 4.70

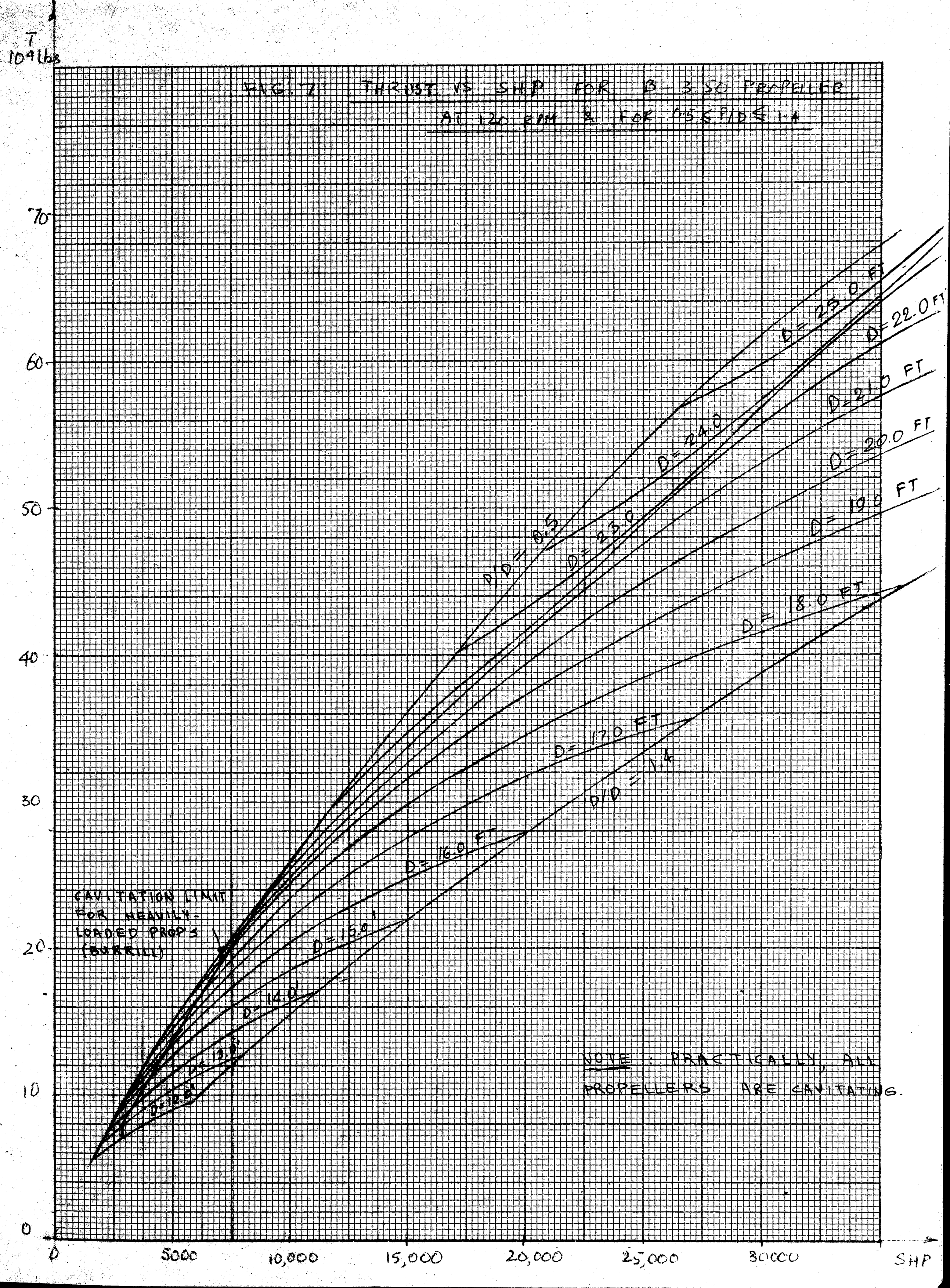


FIG. 7 THRUST VS SHP FOR B 3.50 PROPELLER
AT 120 RPM & FOR 0.5 ≤ P/D ≤ 1.4
T
10^4 lbs
0
10
20
30
40
50
60
70
0
5000
10,000
15,000
20,000
25,000
30000
SHP
D = 25.0 FT
D = 22.0 FT
D = 21.0 FT
D = 20.0 FT
D = 19.0 FT
D = 18.0 FT
D = 24.0
D = 23.0
P/D = 0.5
D = 17.0 FT
P/D = 1.4
D = 16.0 FT
D = 15.0'
D = 14.0'
D = 13.0'
D = 12.0'
CAVITATION LIMIT FOR HEAVILY-LOADED PROPS (BURRILL)
NOTE: PRACTICALLY ALL PROPELLERS ARE CAVITATING.

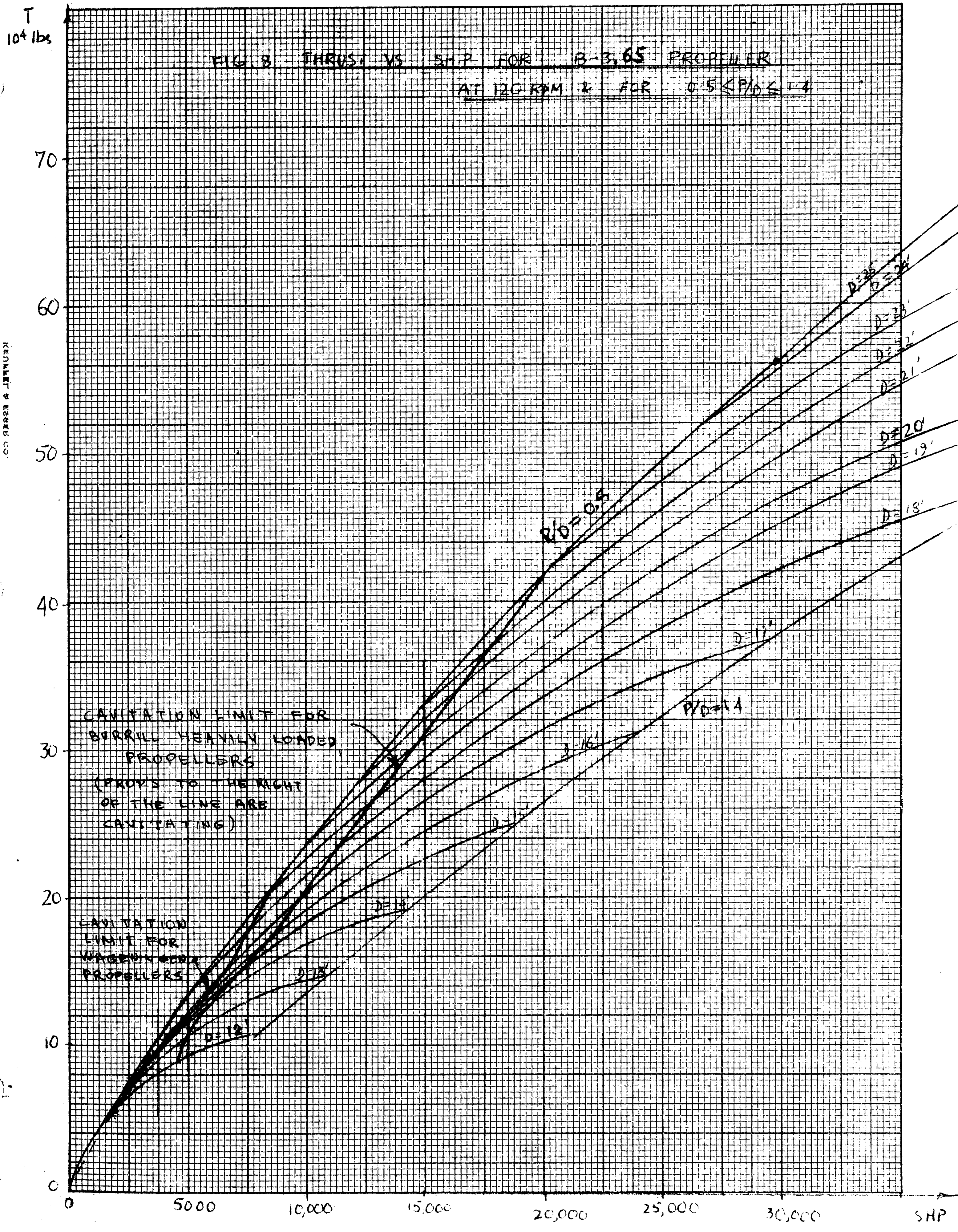


FIG. 8 THRUST VS SHP FOR B-3.65 PROPELLER
AT 120 RPM & FOR 0.5 ≤ P/D ≤ 1.4
T
10⁴ lbs
SHP
P/D = 0.5
P/D = 1.4
D = 25'
D = 24'
D = 23'
D = 22'
D = 21'
D = 20'
D = 19'
D = 18'
D = 17'
D = 16'
D = 15'
D = 14'
D = 13'
D = 12'
CAVITATION LIMIT FOR BURRILL HEAVILY LOADED PROPELLERS (PROPS TO THE RIGHT OF THE LINE ARE CAVITATING)
CAVITATION LIMIT FOR WAGENINGEN PROPELLERS
0
10
20
30
40
50
60
70
5000
10,000
15,000
20,000
25,000
30,000

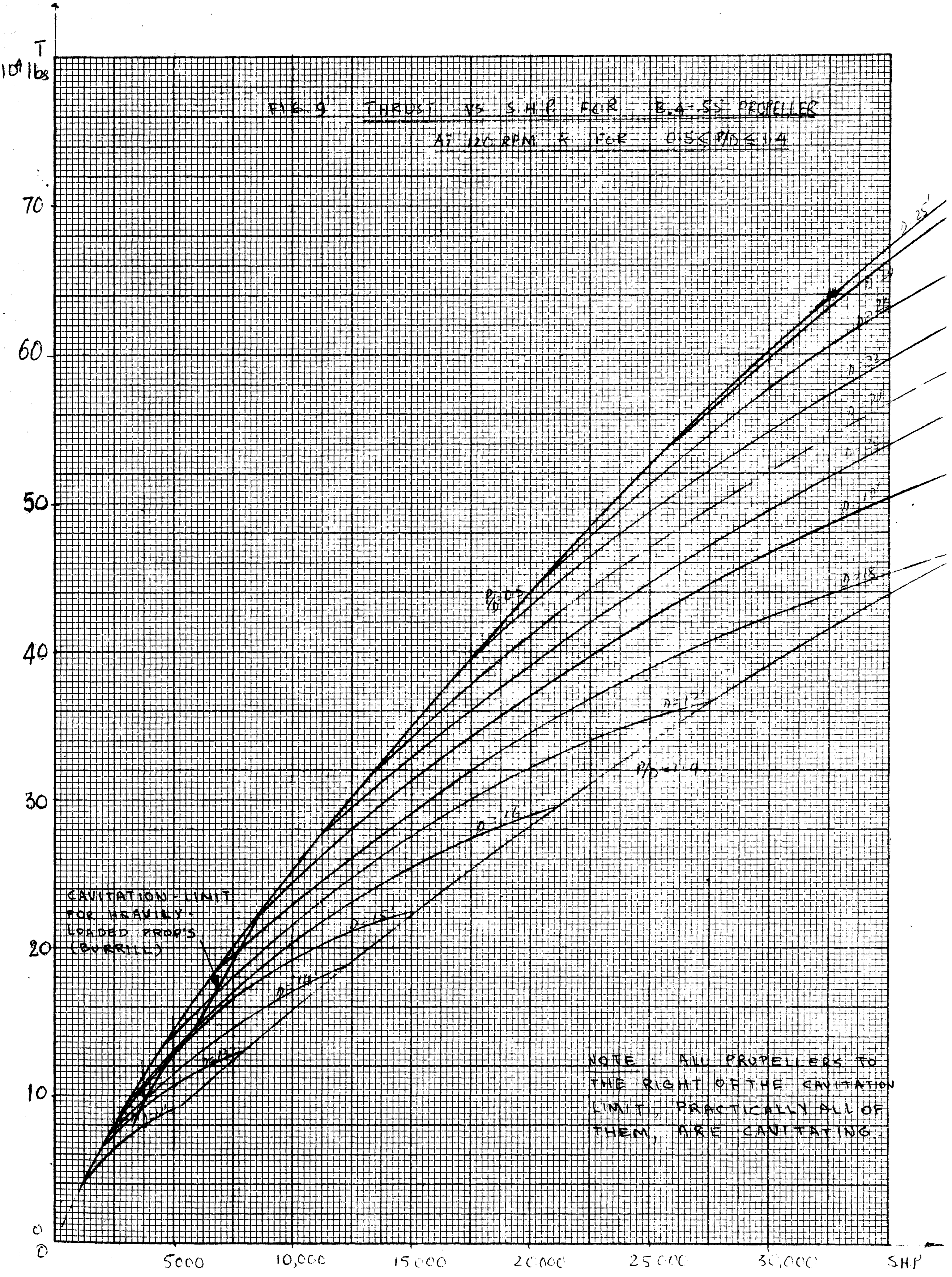


FIG. 9 THRUST VS S.H.P. FOR B.4-55 PROPELLERS AT 120 RPM & FOR 0.5 ≤ P/D ≤ 1.4

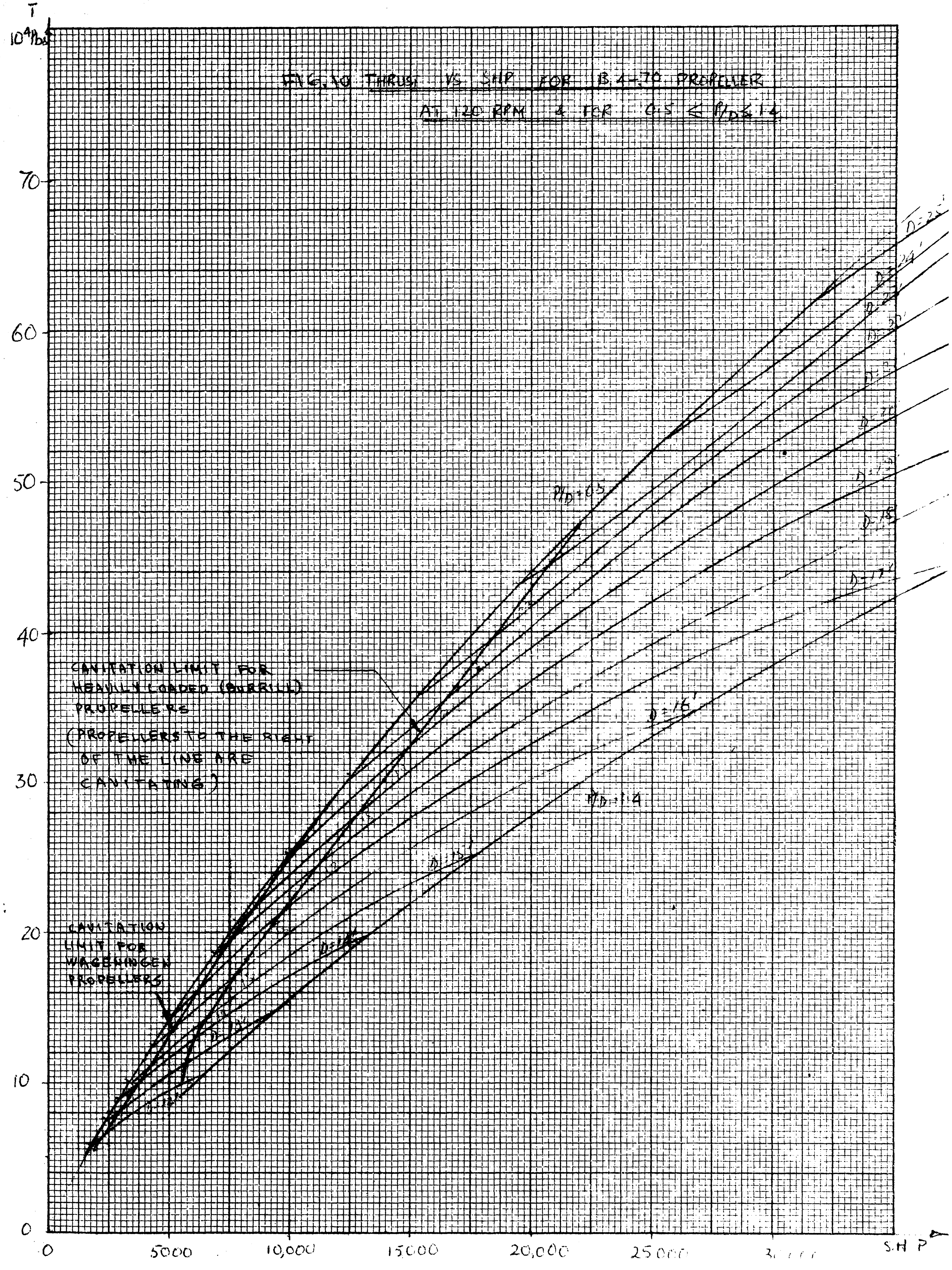


FIG. 10 THRUST VS SHP FOR B 4-70 PROPELLER
AT 120 RPM & FOR 0.5 ≤ P/D ≤ 1.4
T
10⁴ lbs
0
10
20
30
40
50
60
70
0
5000
10,000
15000
20,000
25000
S.H.P.
CAVITATION LIMIT FOR HEAVILY LOADED (BURRILL) PROPELLERS
(PROPELLERS TO THE RIGHT OF THE LINE ARE CAVITATING)
CAVITATION LIMIT FOR WAGENINGEN PROPELLERS
P/D = 0.5
P/D = 1.4
D = 25'
D = 24'
D = 16'
D = 13'
D = 14'

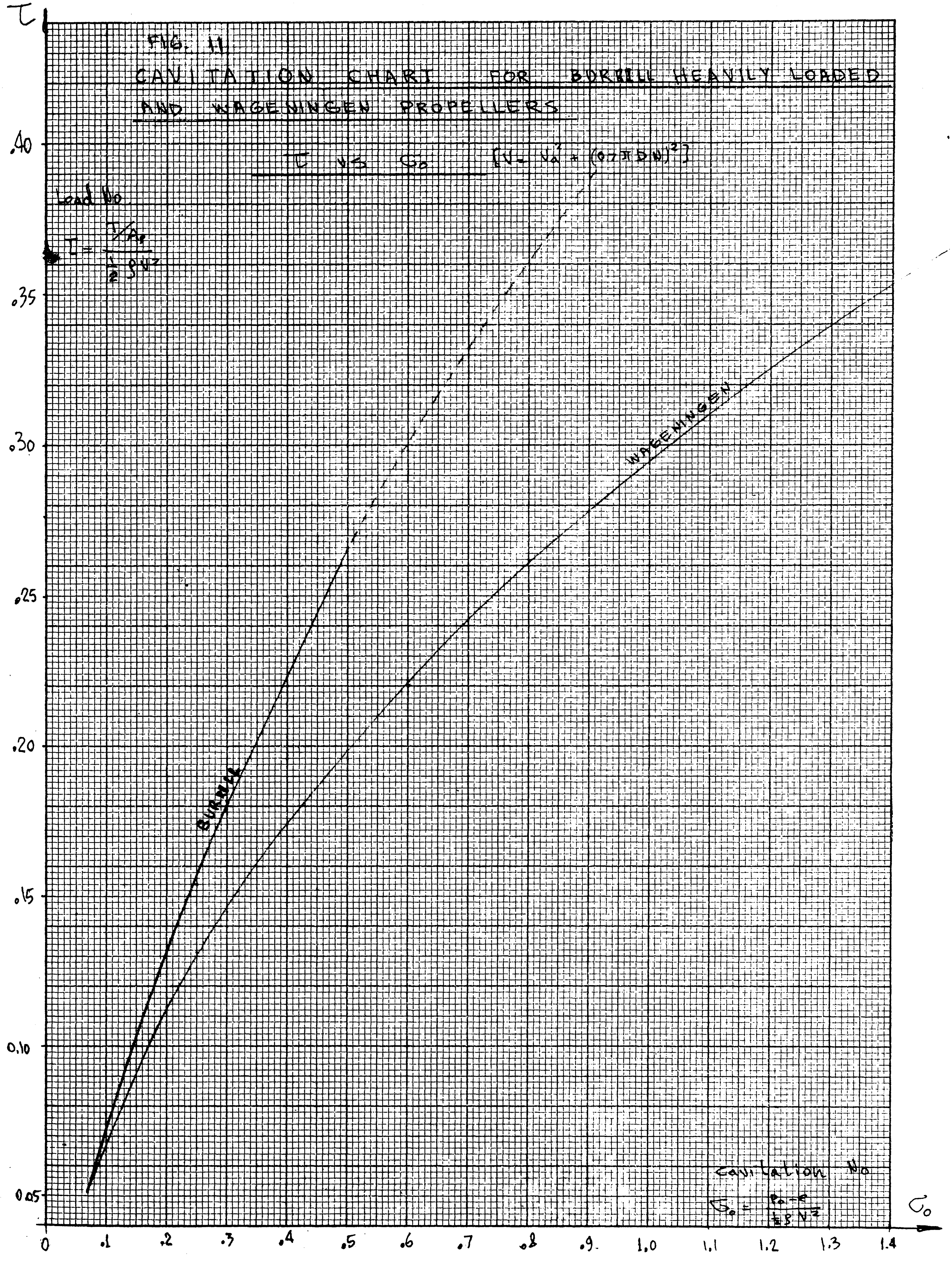
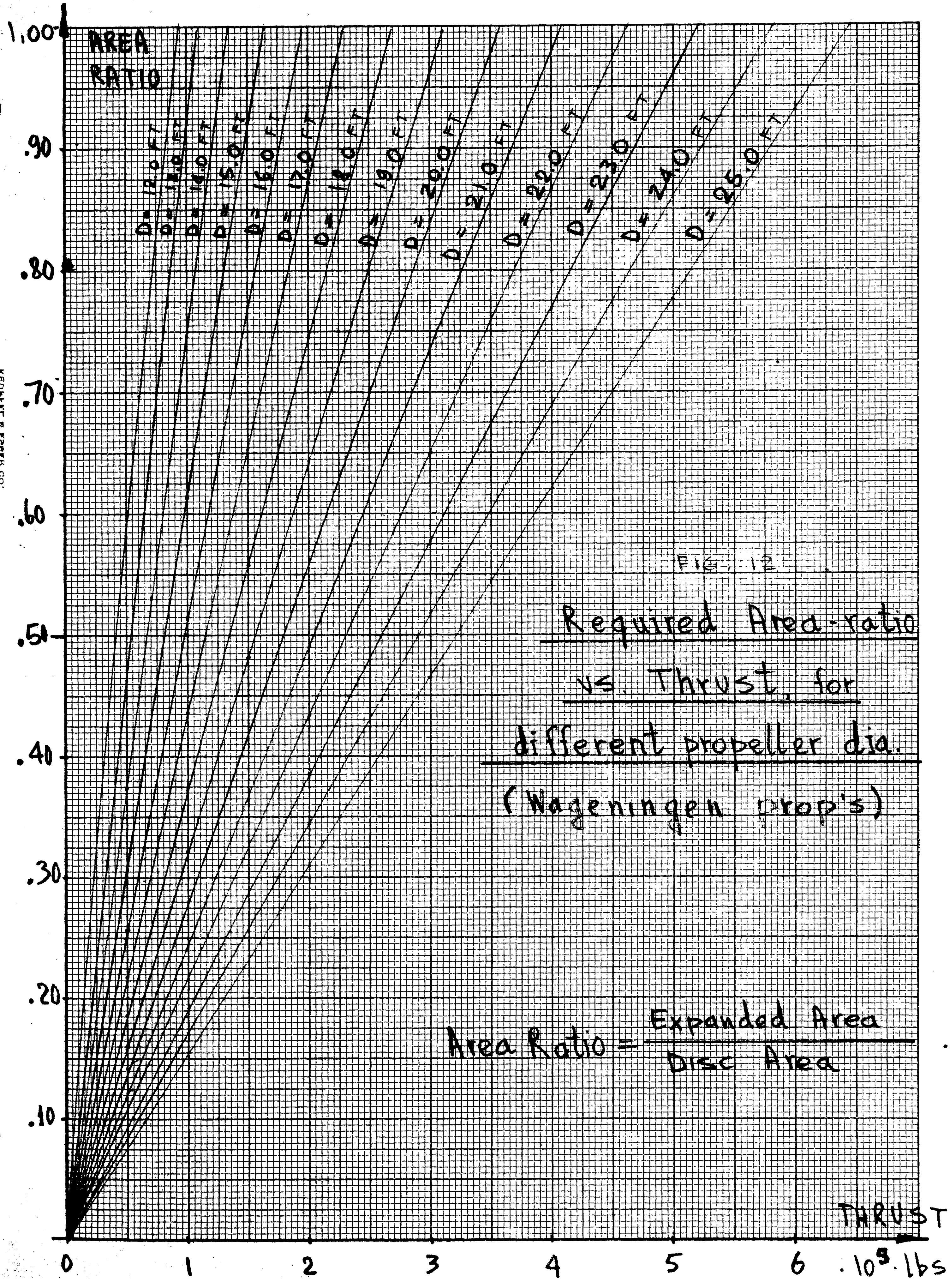


FIG. 11 CAVITATION CHART FOR BORRILL HEAVILY LOADED AND WAGENINGEN PROPELLERS



AREA RATIO
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
D=12.0 FT
D=13.0 FT
D=14.0 FT
D=15.0 FT
D=16.0 FT
D=17.0 FT
D=18.0 FT
D=19.0 FT
D=20.0 FT
D=21.0 FT
D=22.0 FT
D=23.0 FT
D=24.0 FT
D=25.0 FT
FIG. 12
Required Area-ratio vs. Thrust, for different propeller dia.
(Wageningen prop's)
Area Ratio = Expanded Area / Disc Area
THRUST
0
1
2
3
4
5
6
· 10⁵ · lbs

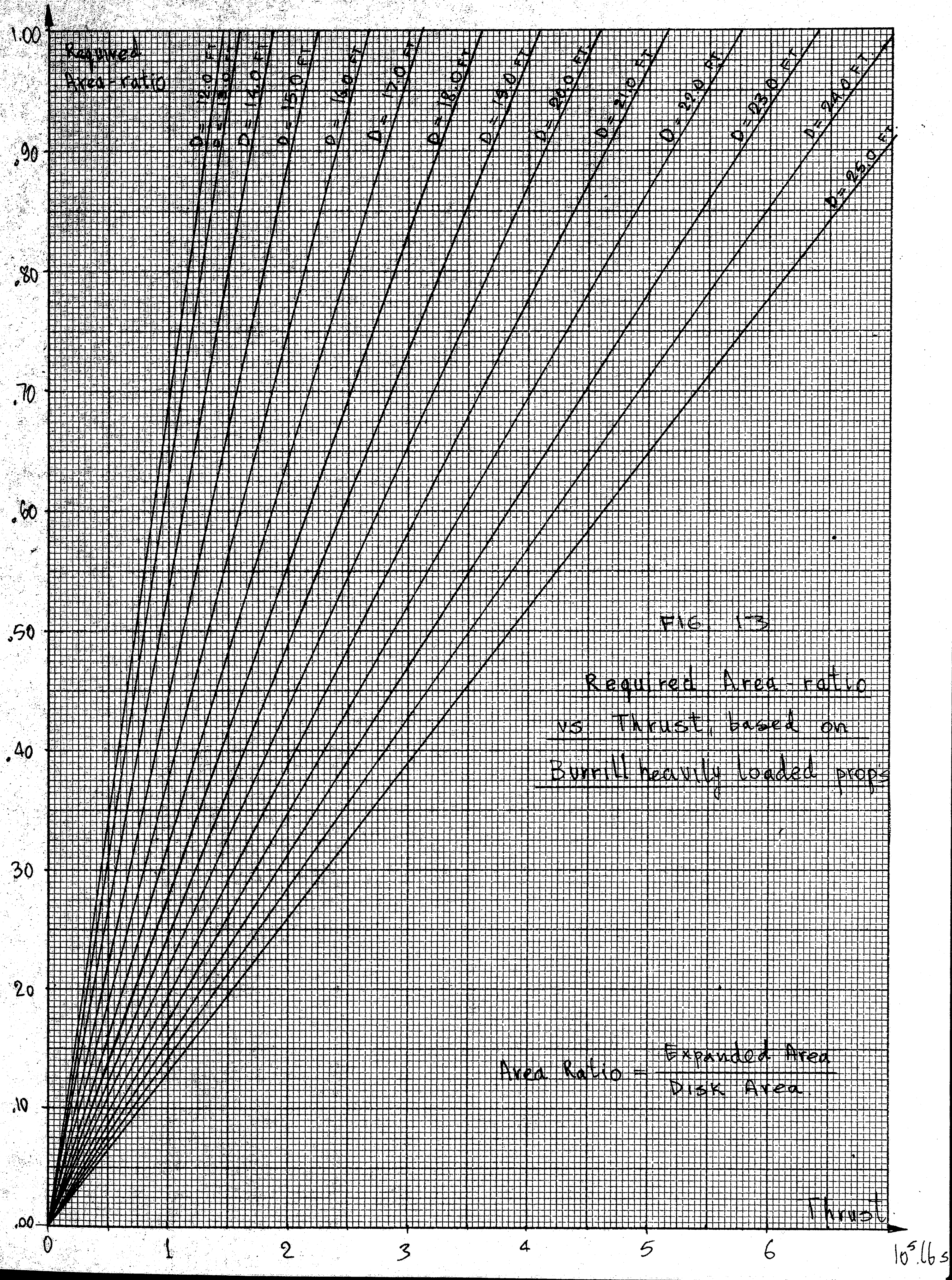


FIG. 13

Required Area ratio vs Thrust, based on Burrill heavily loaded props

FIG. 14 MAX THRUST AND SHP WITHOUT CAVITATION VS SHIP SIZE
FOR B-3.65 PROPELLER
(AVERAGE DIAMETERS)

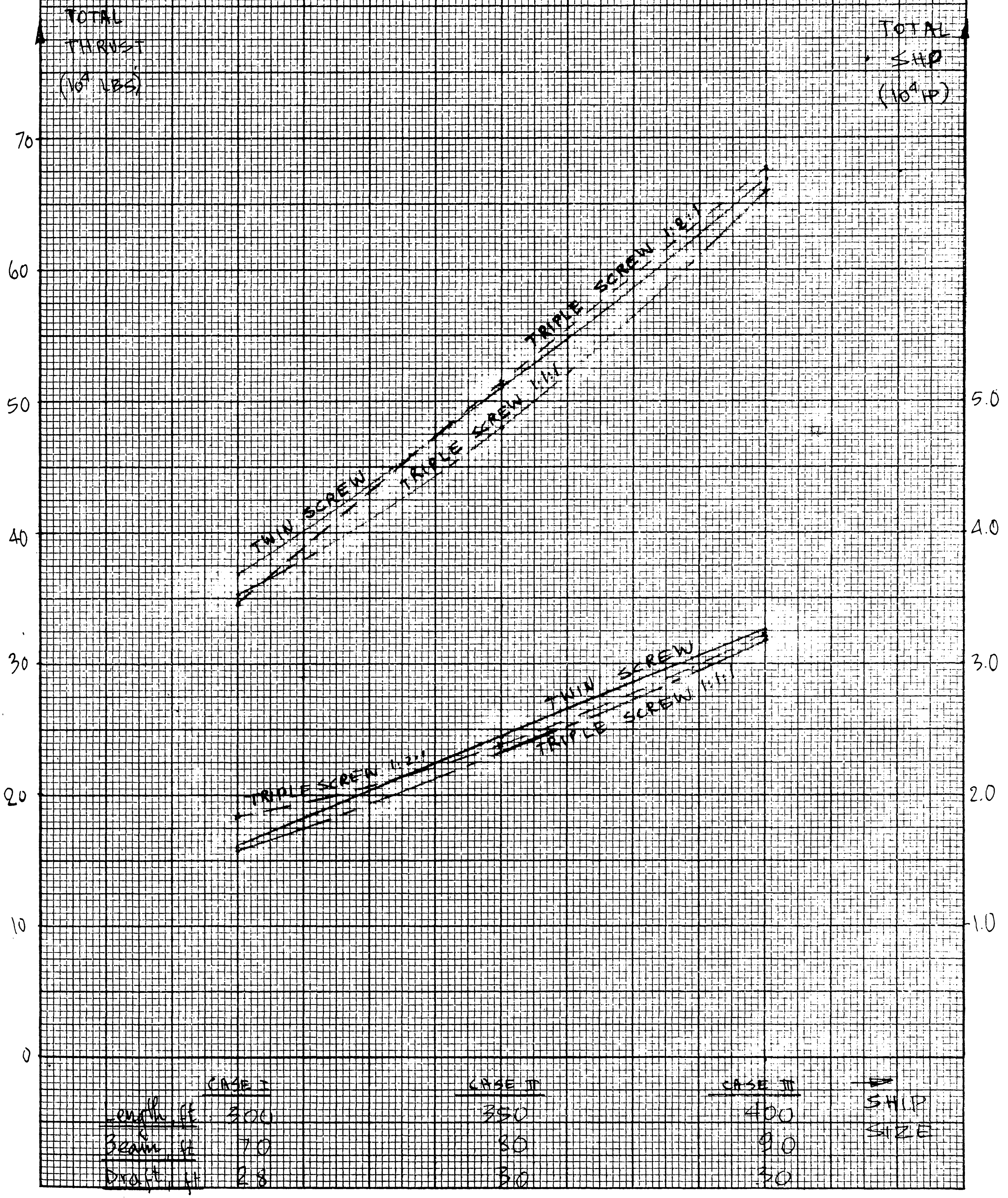
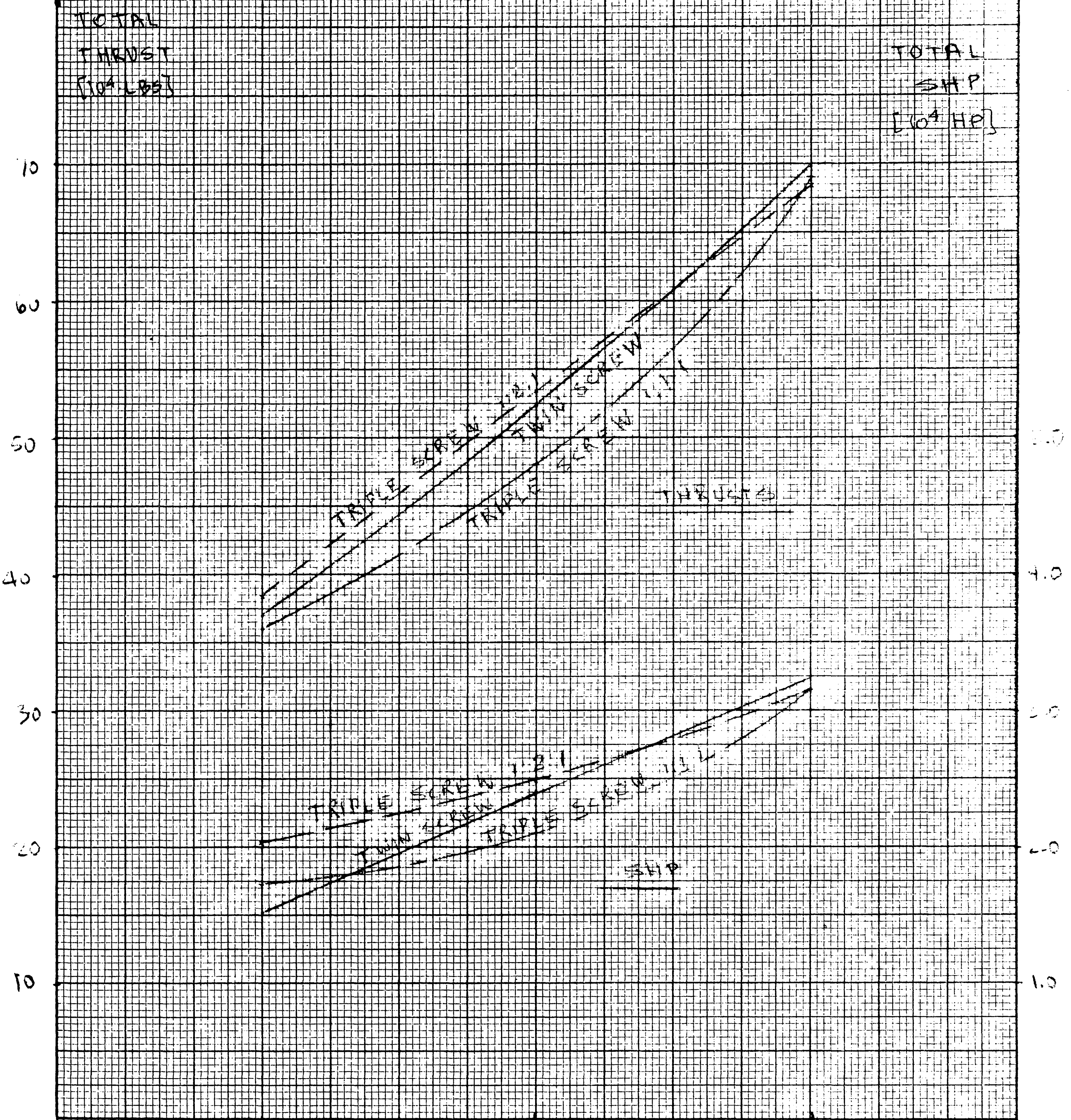


FIGURE 15 MAX. THRUST AND SHP WITHOUT CAVITATION VS. SHIP SIZE - AVERAGE DIAMETER FOR A B-4.70 PROPELLER



	CASE I	CASE II	CASE III
Length, ft	300	350	400
Beam, ft	70	80	90
Draft, ft	28	30	3?

→ SHIP SIZE

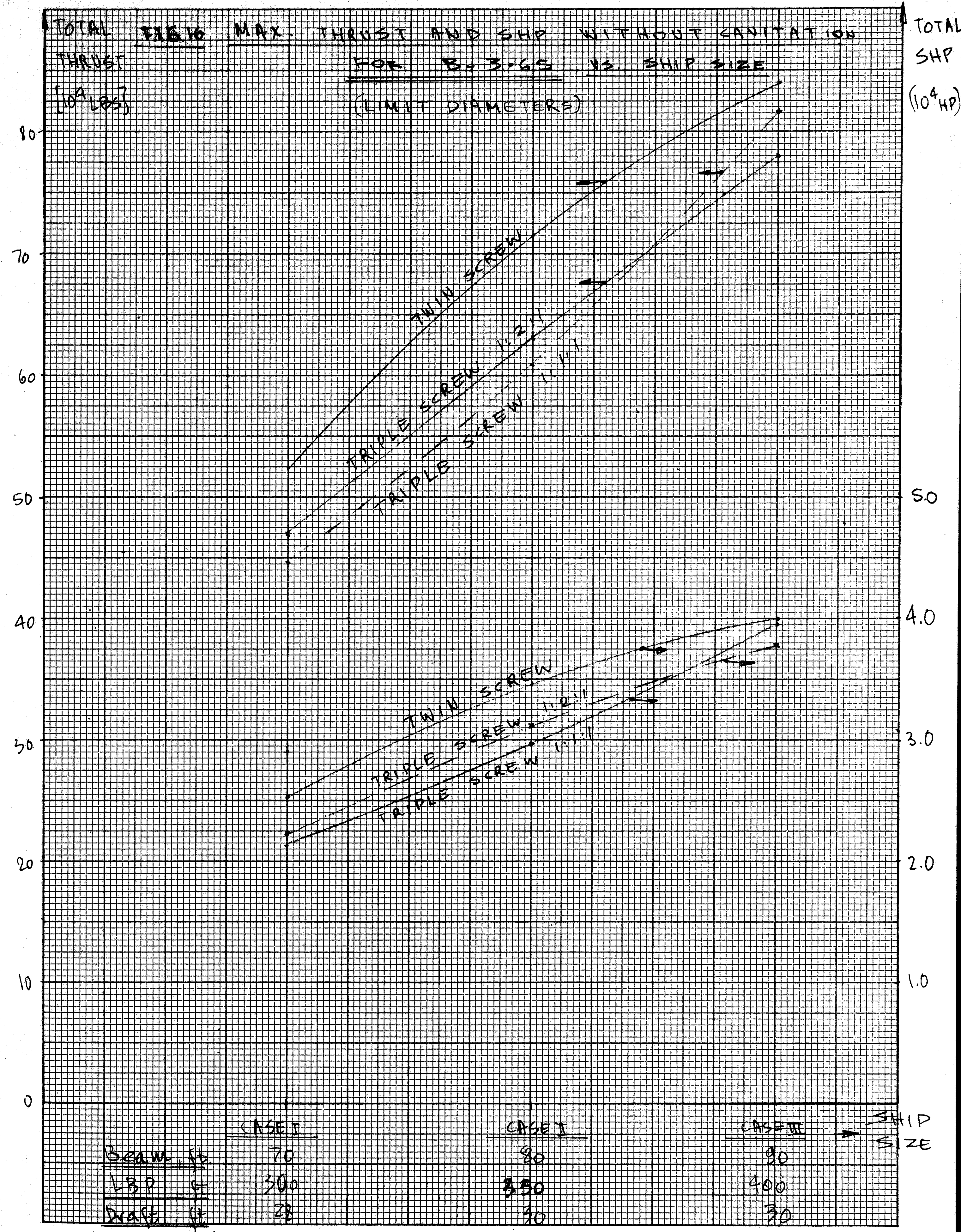
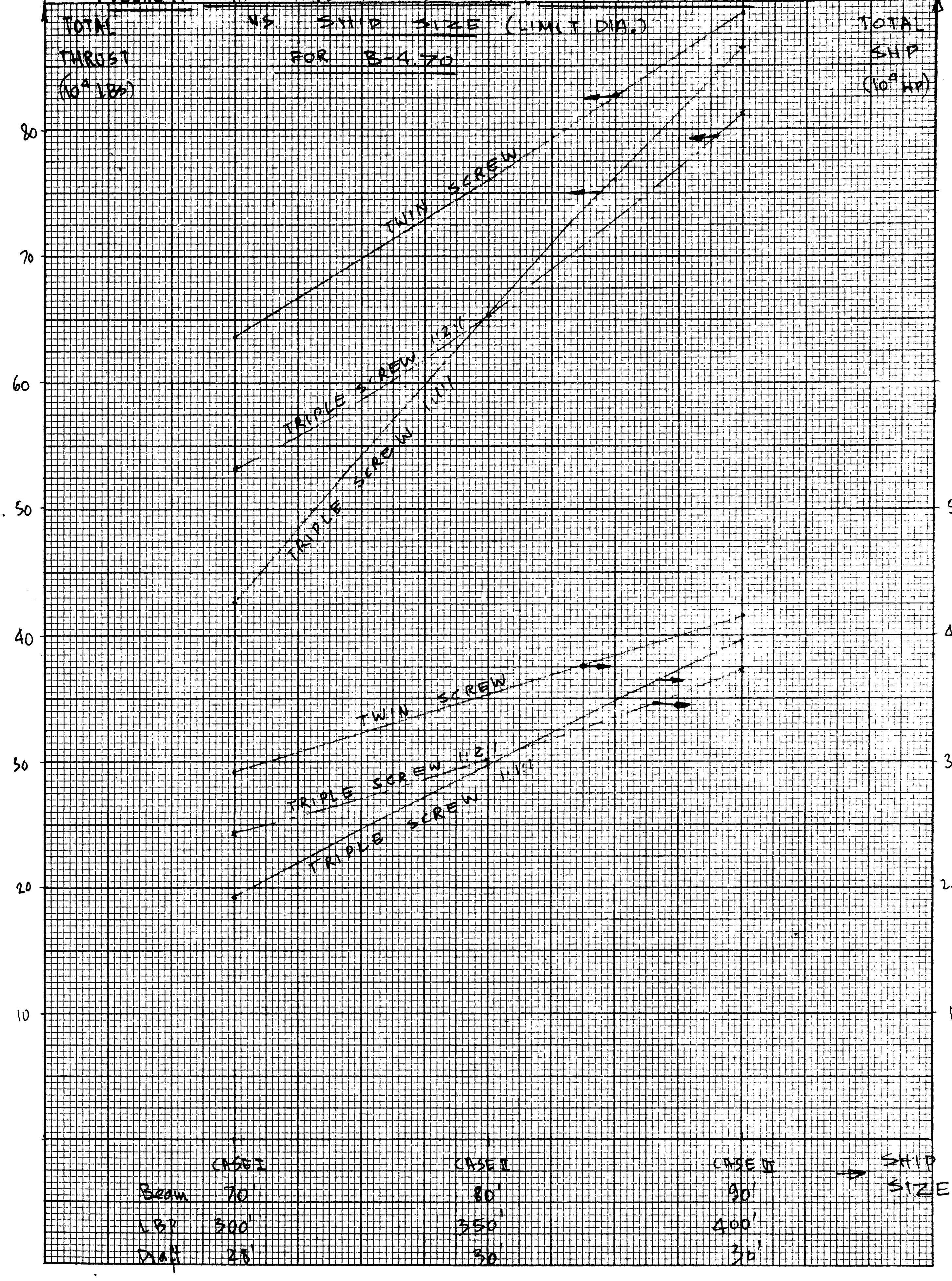
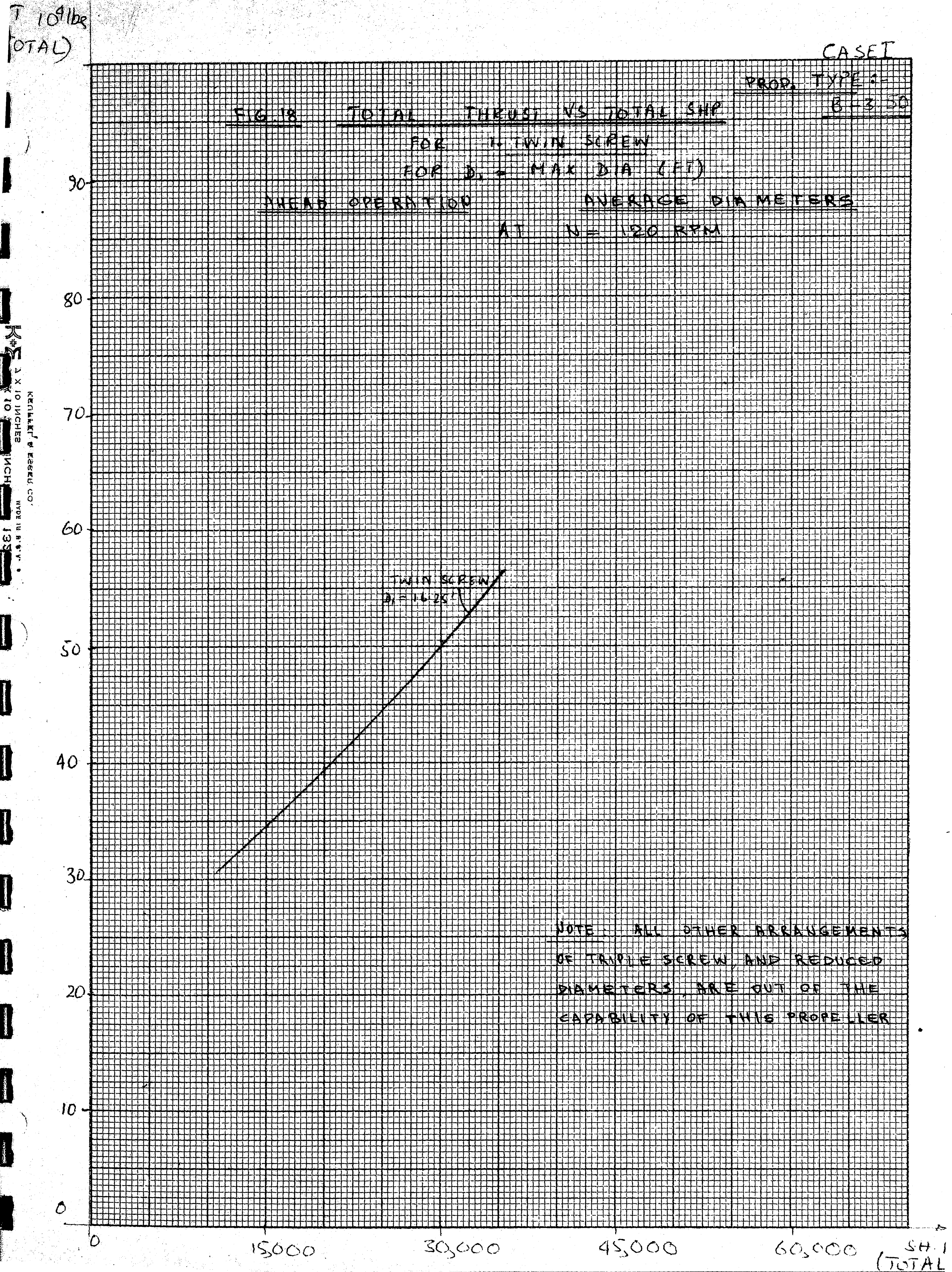
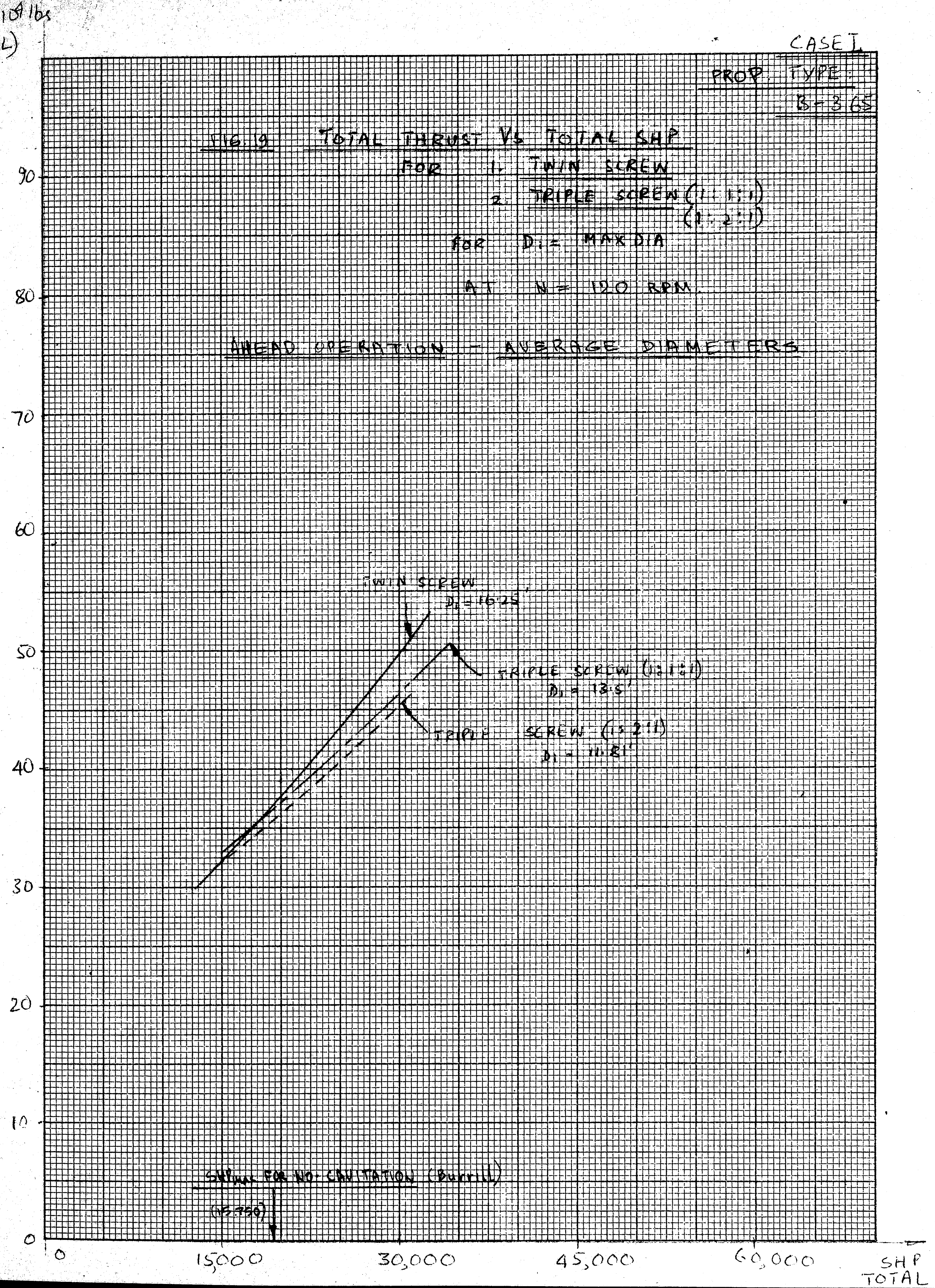


FIG 16 MAX. THRUST AND SHP WITHOUT CAVITATION
FOR B-3-65 vs SHIP SIZE
(LIMIT DIAMETERS)
TOTAL THRUST [10^4 LBS]
TOTAL SHP (10^4 HP)
80
70
60
50
40
30
20
10
0
5.0
4.0
3.0
2.0
1.0
TWIN SCREW
TRIPLE SCREW 1.2:1
TRIPLE SCREW 1:1
TWIN SCREW
TRIPLE SCREW 1.2:1
TRIPLE SCREW 1:1
CASE I
CASE II
CASE III
SHIP SIZE
Beam, ft 70 80 90
LBP ft 300 350 400
Draft ft 28 30 30

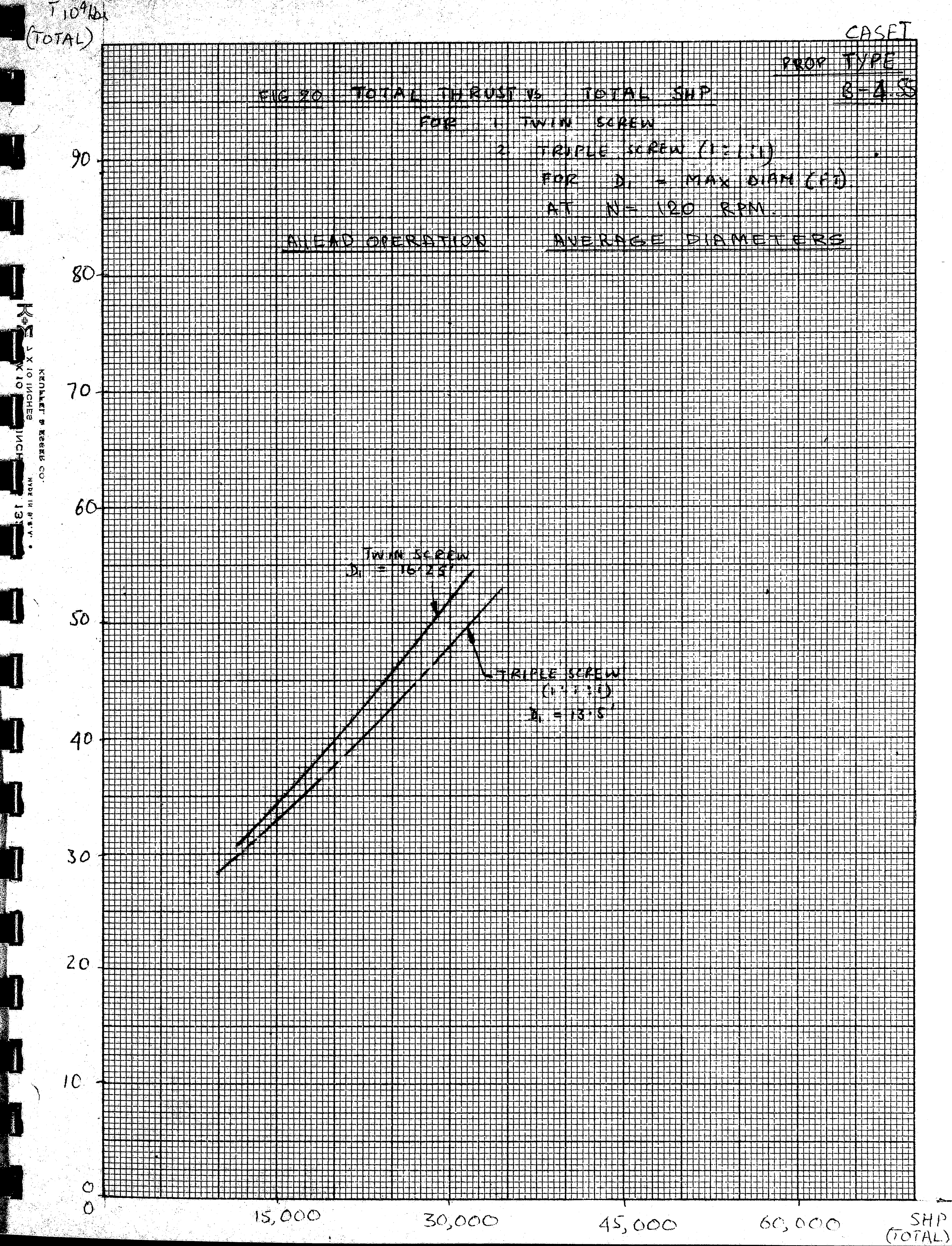
FIGURE 17 MAX THRUST AND SHP (WITHOUT CAVITATION)




CASE I
PROP. TYPE :- B-3.50
FIG. 18 TOTAL THRUST VS TOTAL SHP
FOR 1. TWIN SCREW
FOR D₁ = MAX DIA (FT)
AHEAD OPERATION AVERAGE DIAMETERS
AT N = 120 RPM
T 10³ lbs (TOTAL)
90
80
70
60
50
40
30
20
10
0
TWIN SCREW
D₁ = 16.25'
NOTE ALL OTHER ARRANGEMENTS OF TRIPLE SCREW, AND REDUCED DIAMETERS, ARE OUT OF THE CAPABILITY OF THIS PROPELLER
0
15000
30,000
45,000
60,000
SH.P (TOTAL)


T 10^4 lbs
(TOTAL)
CASE I
PROP. TYPE
B-3 65
FIG. 9 TOTAL THRUST VS TOTAL SHP
FOR 1. TWIN SCREW
2. TRIPLE SCREW (1:1:1)
(1:2:1)
FOR D1 = MAX DIA
AT N = 120 RPM.
AHEAD OPERATION - AVERAGE DIAMETERS
TWIN SCREW
D1 = 16.25'
TRIPLE SCREW (1:1:1)
D1 = 13.5'
TRIPLE SCREW (1:2:1)
D1 = 11.81'
SHPmax FOR NO CAVITATION (Burrill)
(15,750)
0
10
20
30
40
50
60
70
80
90
0
15,000
30,000
45,000
60,000
SHP
TOTAL

CASE I


T 10^4 lbs (TOTAL)
PROP TYPE
B-4.55
FIG 20 TOTAL THRUST vs TOTAL SHP
FOR 1. TWIN SCREW
2. TRIPLE SCREW (1:1:1)
FOR D1 = MAX DIAM (FT)
AT N = 120 RPM.
AHEAD OPERATION
AVERAGE DIAMETERS
TWIN SCREW
D1 = 16.25'
TRIPLE SCREW
(1:1:1)
D1 = 13.5'
90
80
70
60
50
40
30
20
10
0
0
15,000
30,000
45,000
60,000
SHP (TOTAL)

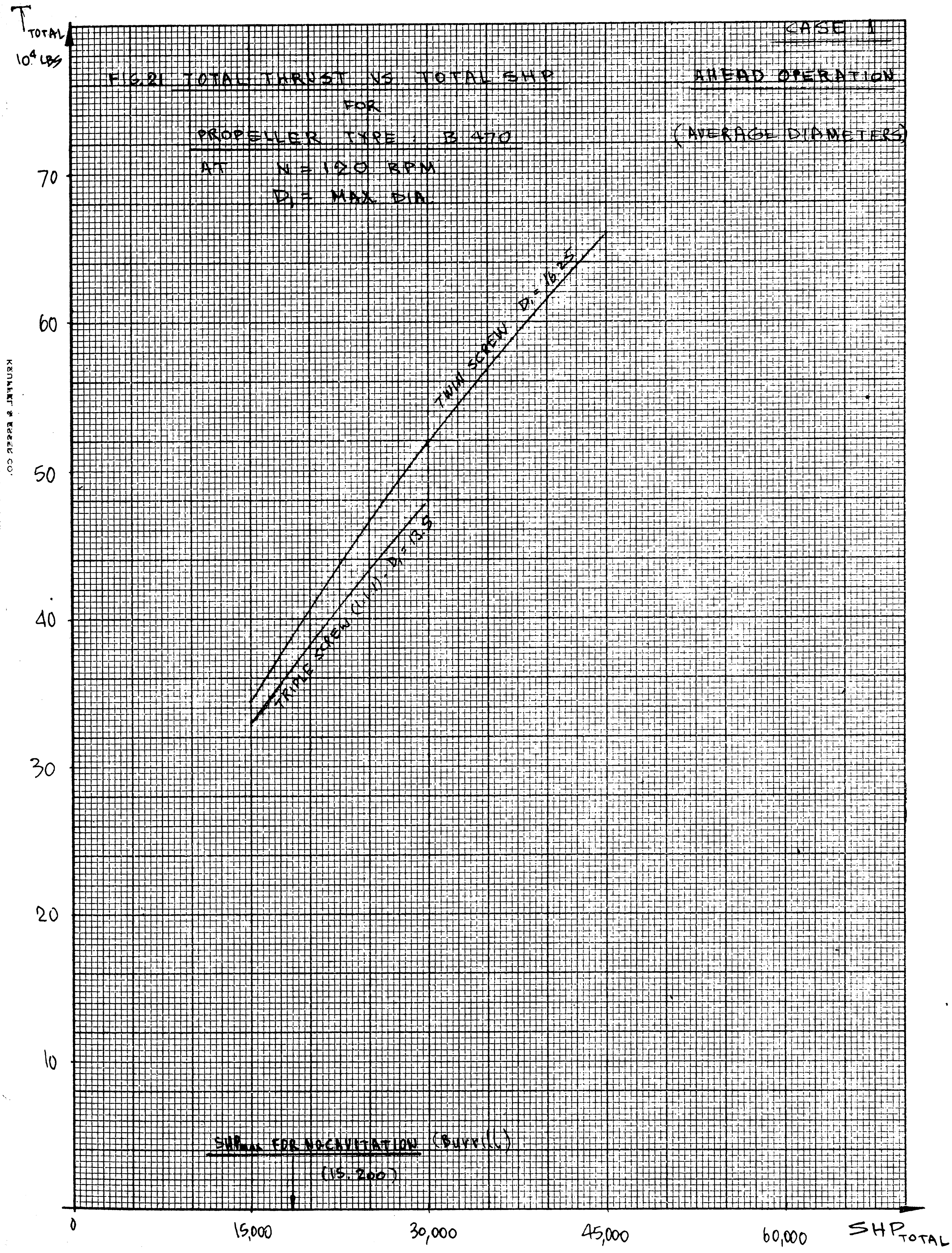
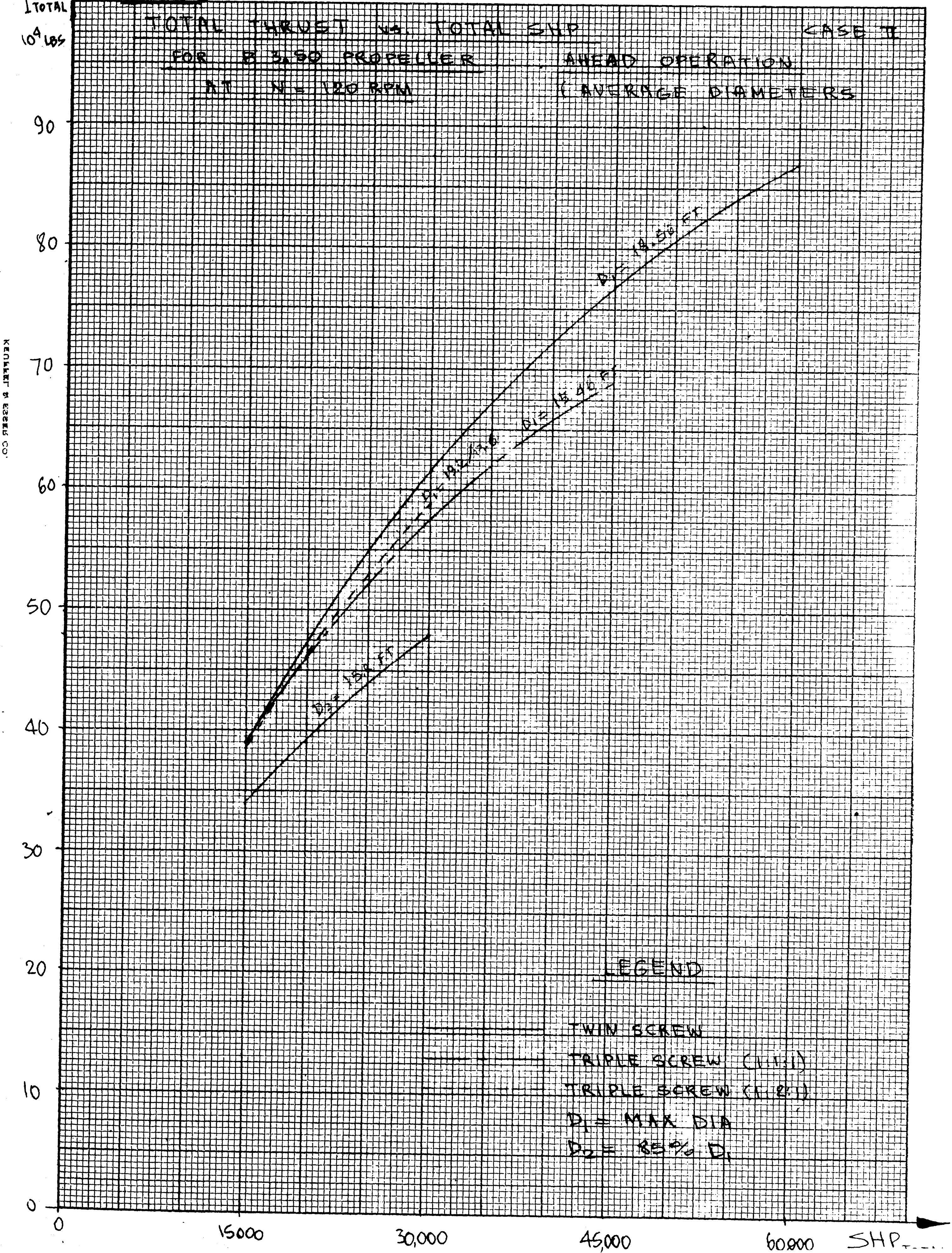


FIG. 21 TOTAL THRUST VS TOTAL SHP
FOR
PROPELLER TYPE : B 470
AT N = 120 RPM
D1 = MAX DIA
CASE 1
AHEAD OPERATION
(AVERAGE DIAMETERS)
T TOTAL
10^4 LBS
70
60
50
40
30
20
10
0
15,000
30,000
45,000
60,000
SHP TOTAL
TWIN SCREW D1 = 16.25
TRIPLE SCREW (1.1) D1 = 13.5
SHPmax FOR NO CAVITATION (Burrill)
(15,200)

FIG. 22



T TOTAL
10^4 LBS
TOTAL THRUST vs. TOTAL SHP
FOR B 3.50 PROPELLER
AT N = 120 RPM
CASE II
AHEAD OPERATION
(AVERAGE DIAMETERS
90
80
70
60
50
40
30
20
10
0
15000
30,000
45,000
60,000
SHP
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D1 = MAX DIA
D2 = 85% D1

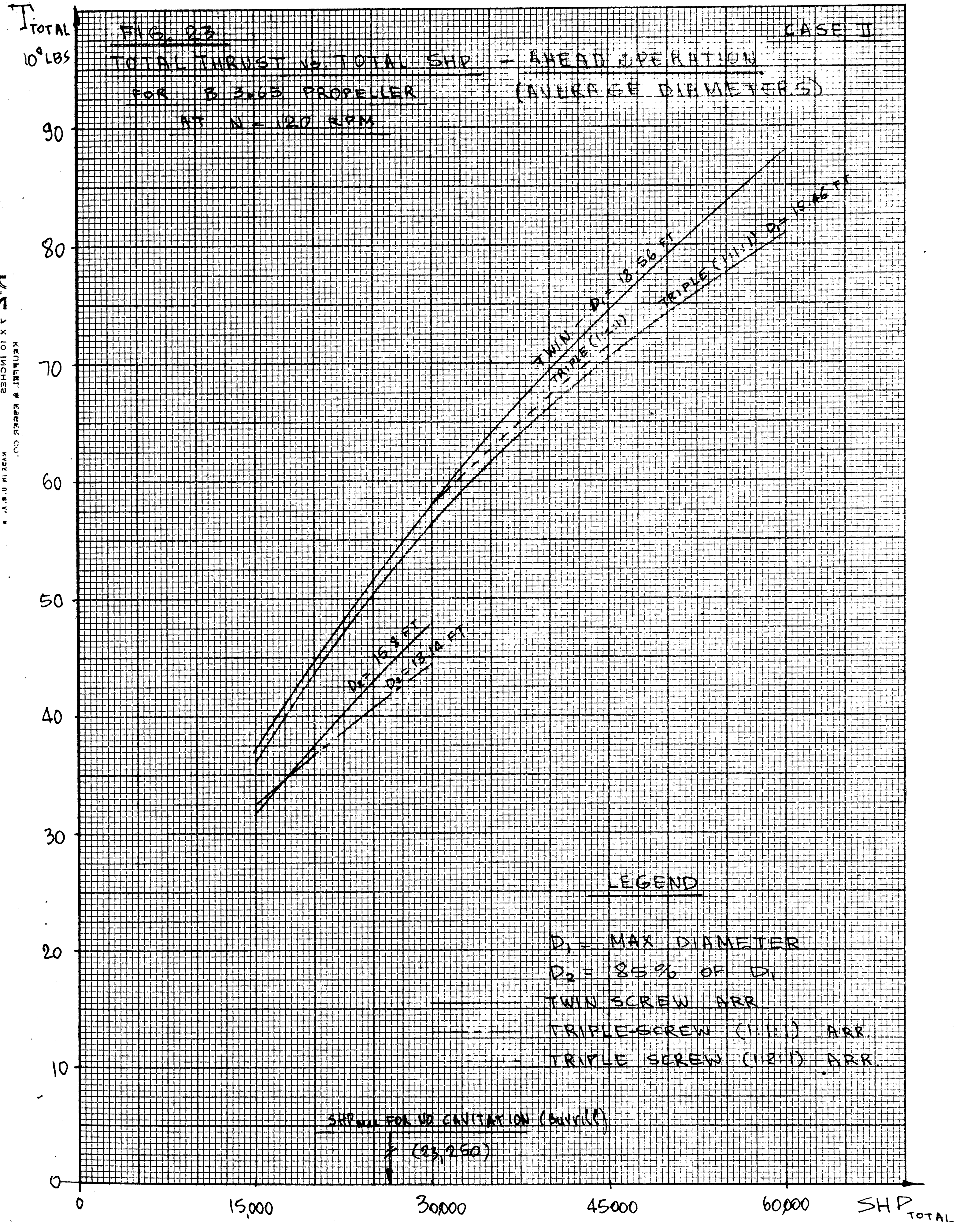
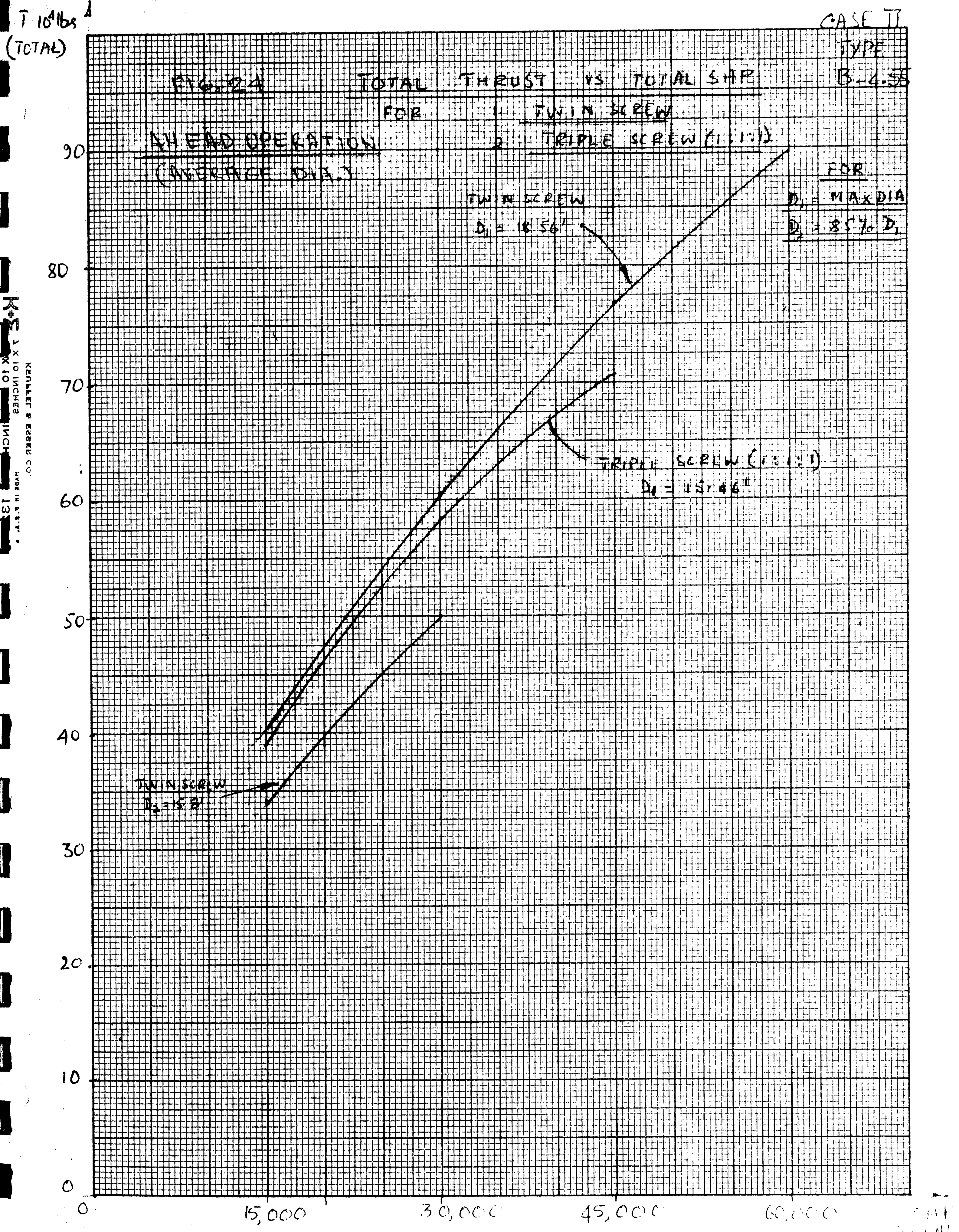


FIG. 23
CASE II
TOTAL THRUST vs. TOTAL SHP - AHEAD OPERATION
FOR B 3.65 PROPELLER
(AVERAGE DIAMETERS)
AT N = 120 RPM
T_{TOTAL} 10^4 LBS
SHP_{TOTAL}
0
15,000
30,000
45000
60,000
10
20
30
40
50
60
70
80
90
TWIN - D_1 = 18.56 FT
TRIPLE (1:1:1) D_1 = 15.46 FT
TRIPLE (1:2:1)
D_2 = 15.8 FT
D_2 = 13.14 FT
LEGEND
D_1 = MAX DIAMETER
D_2 = 85 % OF D_1
TWIN SCREW ARR
TRIPLE-SCREW (1:1:1) ARR
TRIPLE SCREW (1:2:1) ARR
SHP_{MAX} FOR NO CAVITATION (Burrill)
(23,250)



T 10^4 lbs (TOTAL)
CASE II
TYPE B-4.55
FIG. 24
TOTAL THRUST vs TOTAL SHP
FOR 1 TWIN SCREW
2 TRIPLE SCREW (1:1:1)
AHEAD OPERATION
(AVERAGE DIA.)
FOR
D1 = MAX DIA
D2 = 85% D1
TWIN SCREW D1 = 18.56'
TRIPLE SCREW (1:1:1) D1 = 15.46'
TWIN SCREW D2 = 15.8'
0
10
20
30
40
50
60
70
80
90
0
15,000
30,000
45,000
60,000

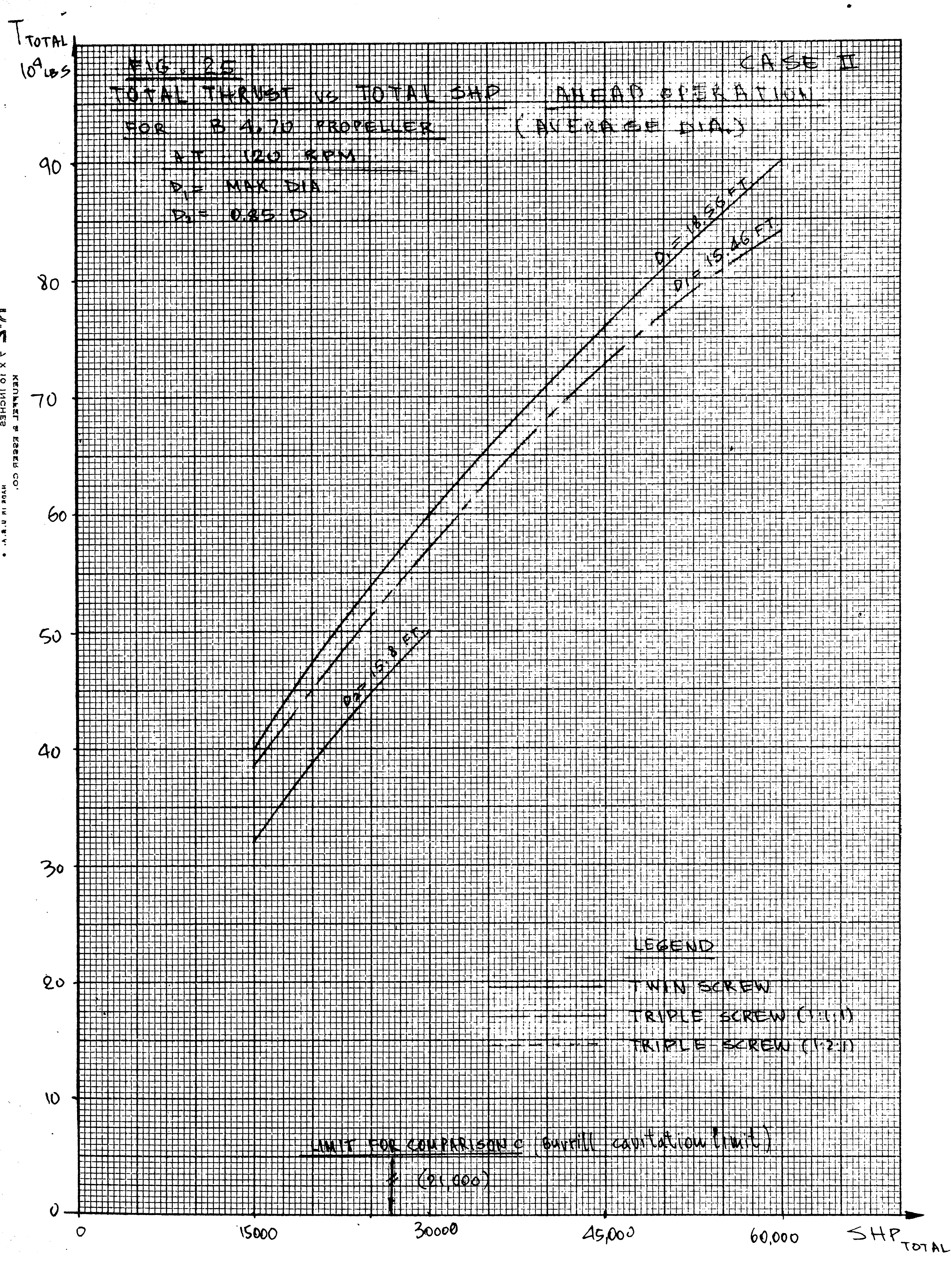


FIG. 25
CASE II
TOTAL THRUST VS TOTAL SHP AHEAD OPERATION
FOR B 4.70 PROPELLER (AVERAGE DIA.)
AT 120 RPM
D1 = MAX DIA
D2 = 0.85 D
T TOTAL 10^4 LBS
D1 = 18.56 FT
D1 = 15.46 FT
D2 = 15.8 FT
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
LIMIT FOR COMPARISON (Burrill cavitation limit)
(27,000)
0
10
20
30
40
50
60
70
80
90
0
15000
30000
45,000
60,000
SHP TOTAL

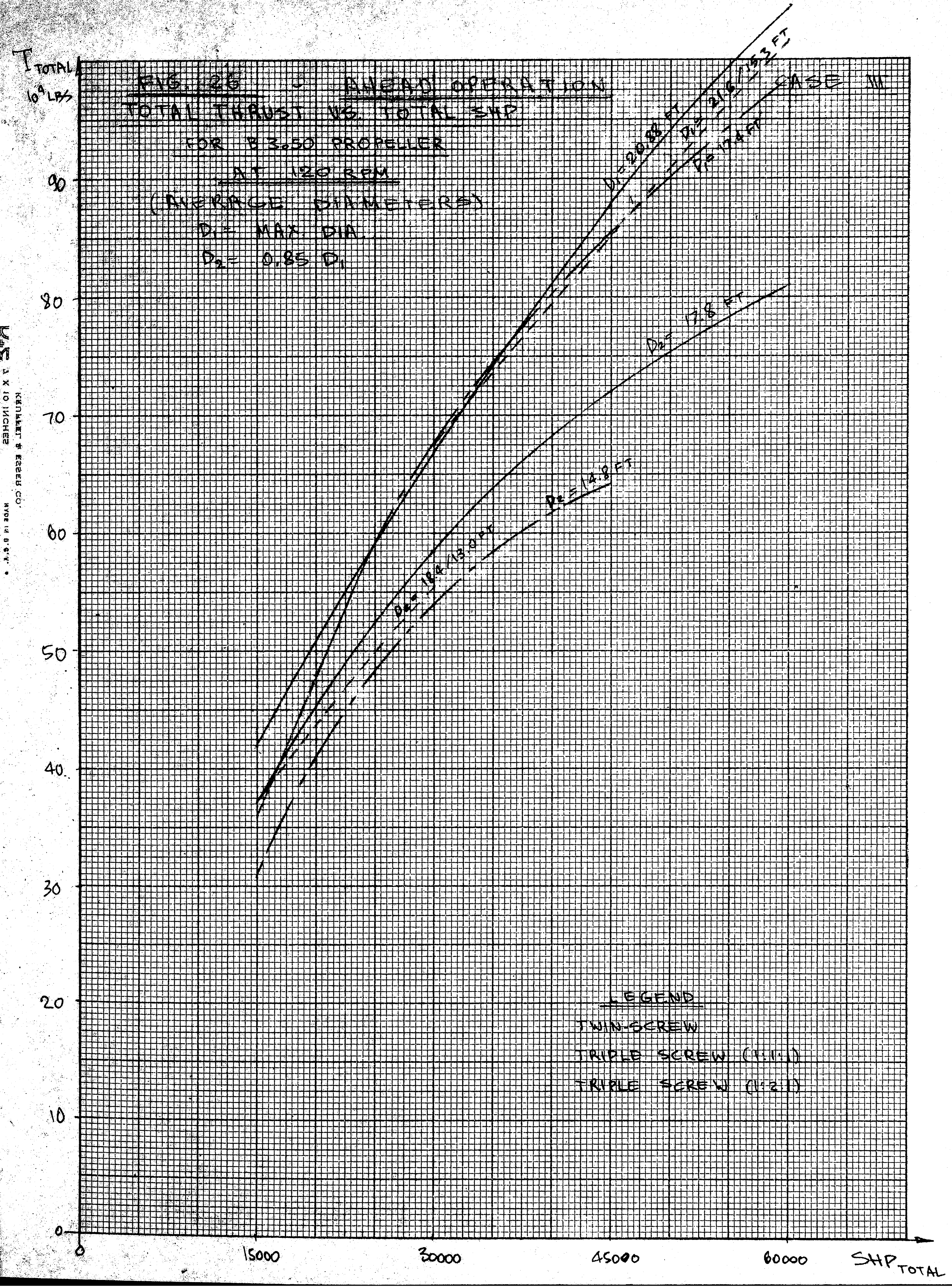


FIG. 26 - AHEAD OPERATION
TOTAL THRUST VS. TOTAL SHP
FOR B 3.50 PROPELLER
AT 120 RPM
(AVERAGE DIAMETERS)
D1 = MAX. DIA.
D2 = 0.85 D1
CASE III
T TOTAL 10^3 LBS
SHP TOTAL
0
10
20
30
40
50
60
70
80
90
15000
30000
45000
60000
D1 = 20.88 FT
D1 = 21.6 / 15.3 FT
D1 = 17.4 FT
D2 = 17.8 FT
D2 = 14.8 FT
D2 = 18.4 / 13.0 FT
LEGEND
TWIN-SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
KEUFFEL & ESSER CO.
10 X 10 TO 1/2 INCH
7 X 10 INCHES
MADE IN U.S.A.

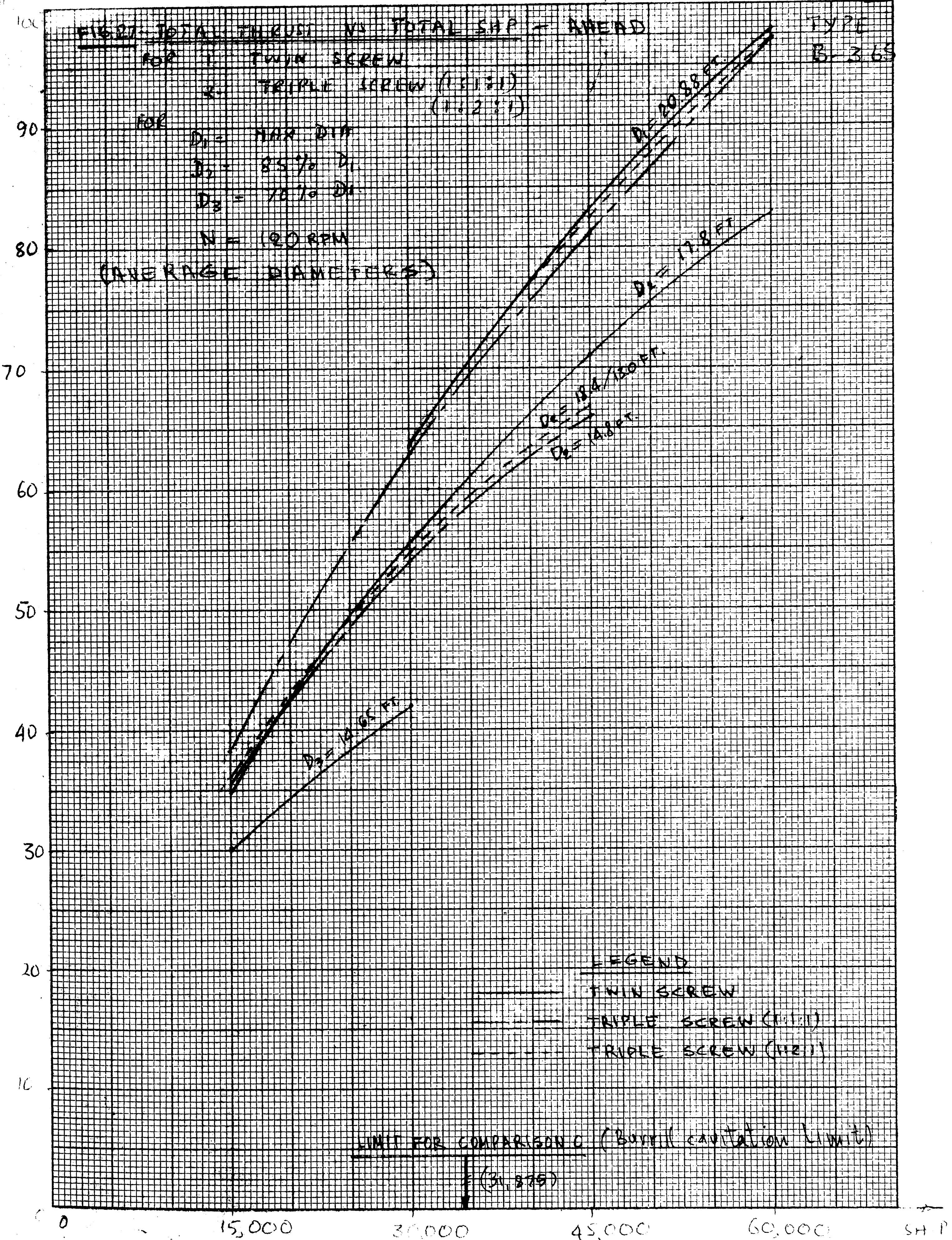
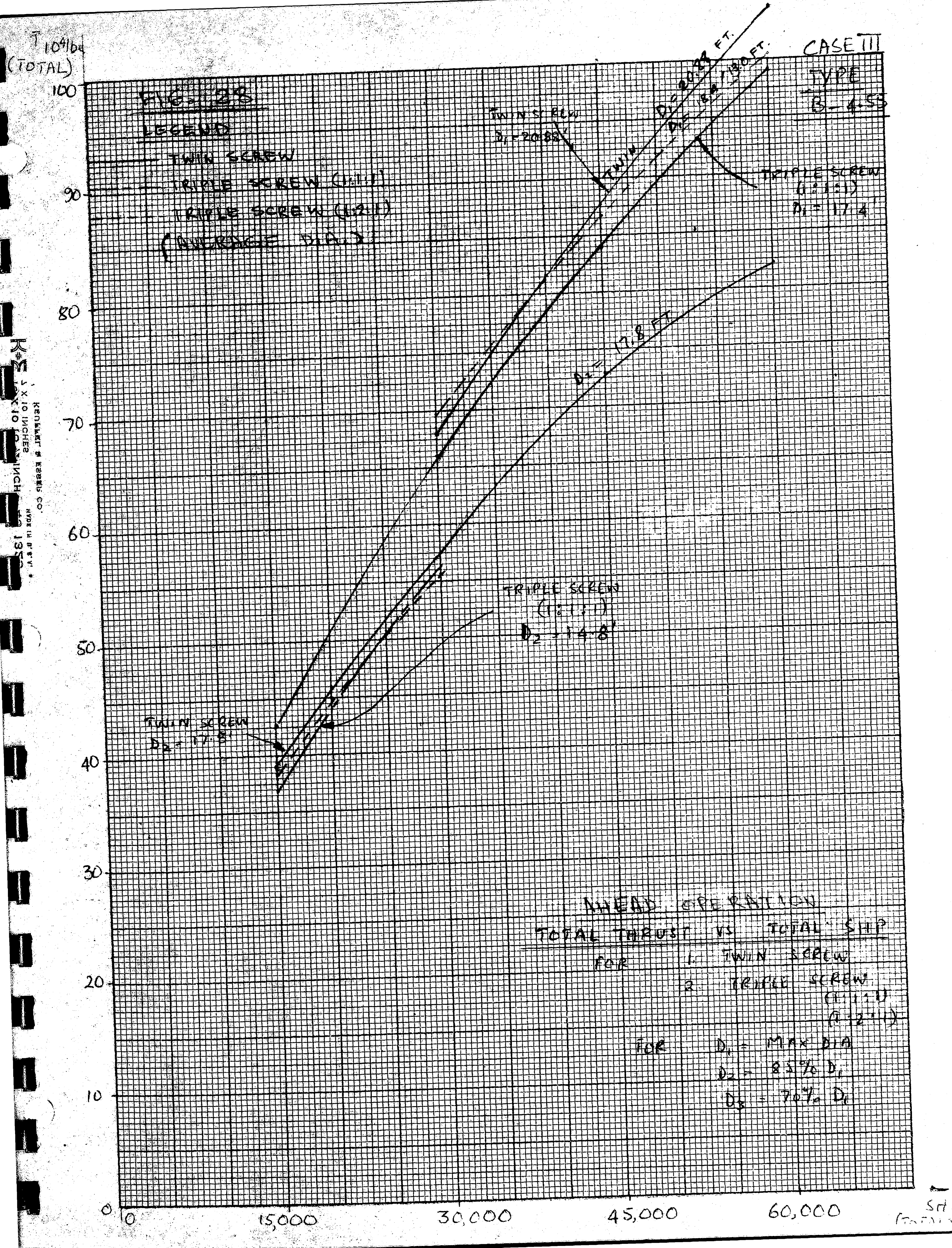


FIG 27 - TOTAL THRUST VS TOTAL SHP - AHEAD
FOR 1. TWIN SCREW
2. TRIPLE SCREW (1:1:1)
(1:2:1)
TYPE B-3.65
FOR D1 = MAX DIA
D2 = 85% D1
D3 = 70% D1
N = 120 RPM
(AVERAGE DIAMETERS)
D1 = 20.88 FT.
D1 = 17.8 FT
D2 = 18.4/120 FT.
D2 = 14.8 FT.
D3 = 12.65 FT
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
LIMIT FOR COMPARISON (Burrill cavitation limit)
(31,875)
100
90
80
70
60
50
40
30
20
10
0
15,000
30,000
45,000
60,000
SHP



T 10⁴ lbs (TOTAL)
FIG. 28
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
(AVERAGE DIA.)
CASE III
TYPE B-4.55
D₁ = 20.88 FT.
TWIN SCREW D₁ = 20.88'
TWIN
TRIPLE SCREW (1:1:1) D₁ = 17.4'
D₂ = 17.8 FT
TRIPLE SCREW (1:1:1) D₂ = 14.8'
TWIN SCREW D₂ = 17.8'
AHEAD OPERATION
TOTAL THRUST VS TOTAL SHP
FOR 1. TWIN SCREW
2. TRIPLE SCREW (1:1:1) (1:2:1)
FOR D₁ = MAX DIA
D₂ = 85% D₁
D₃ = 70% D₁
0
10
20
30
40
50
60
70
80
90
100
15,000
30,000
45,000
60,000
SHP (TOTAL)

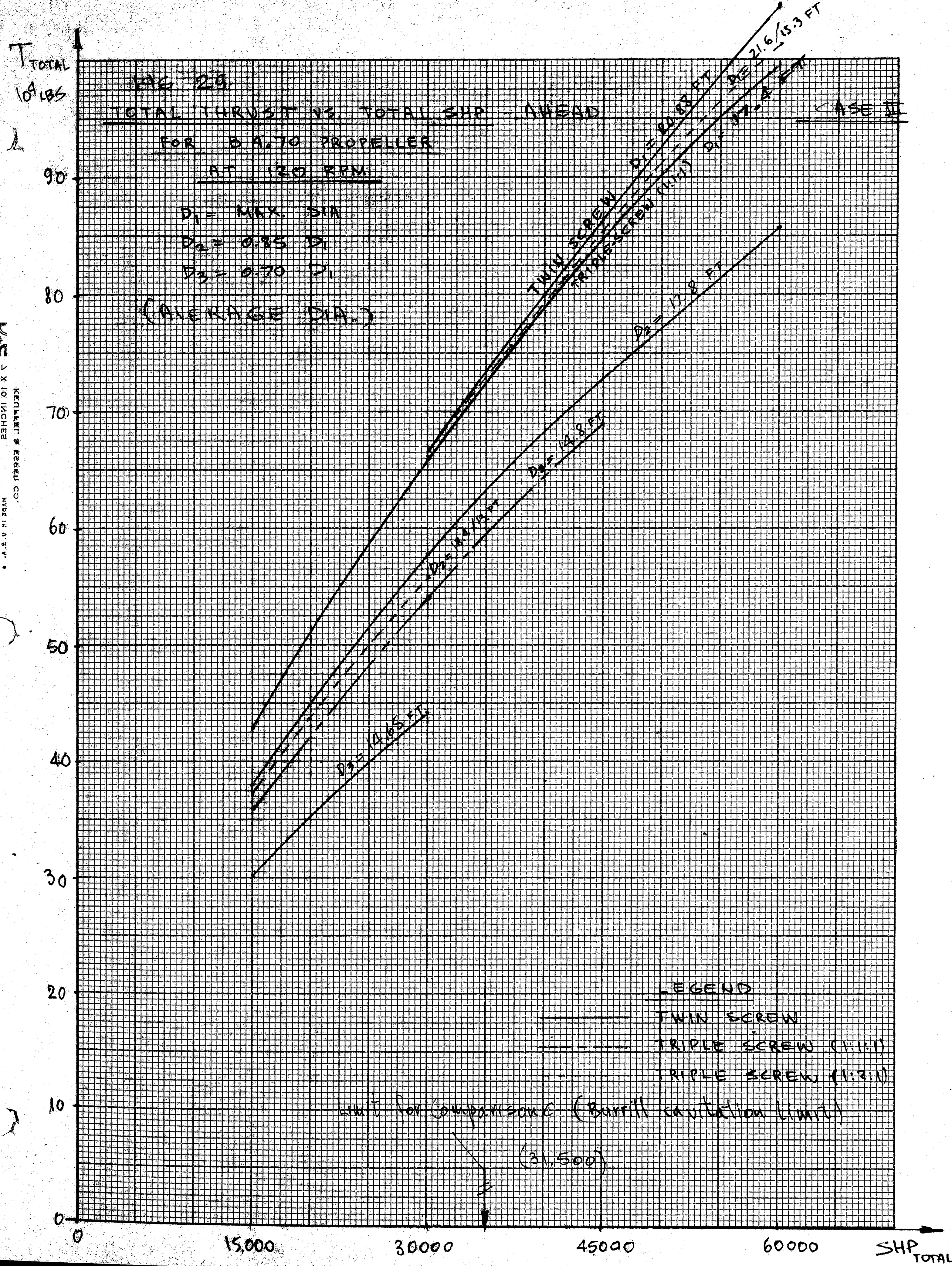


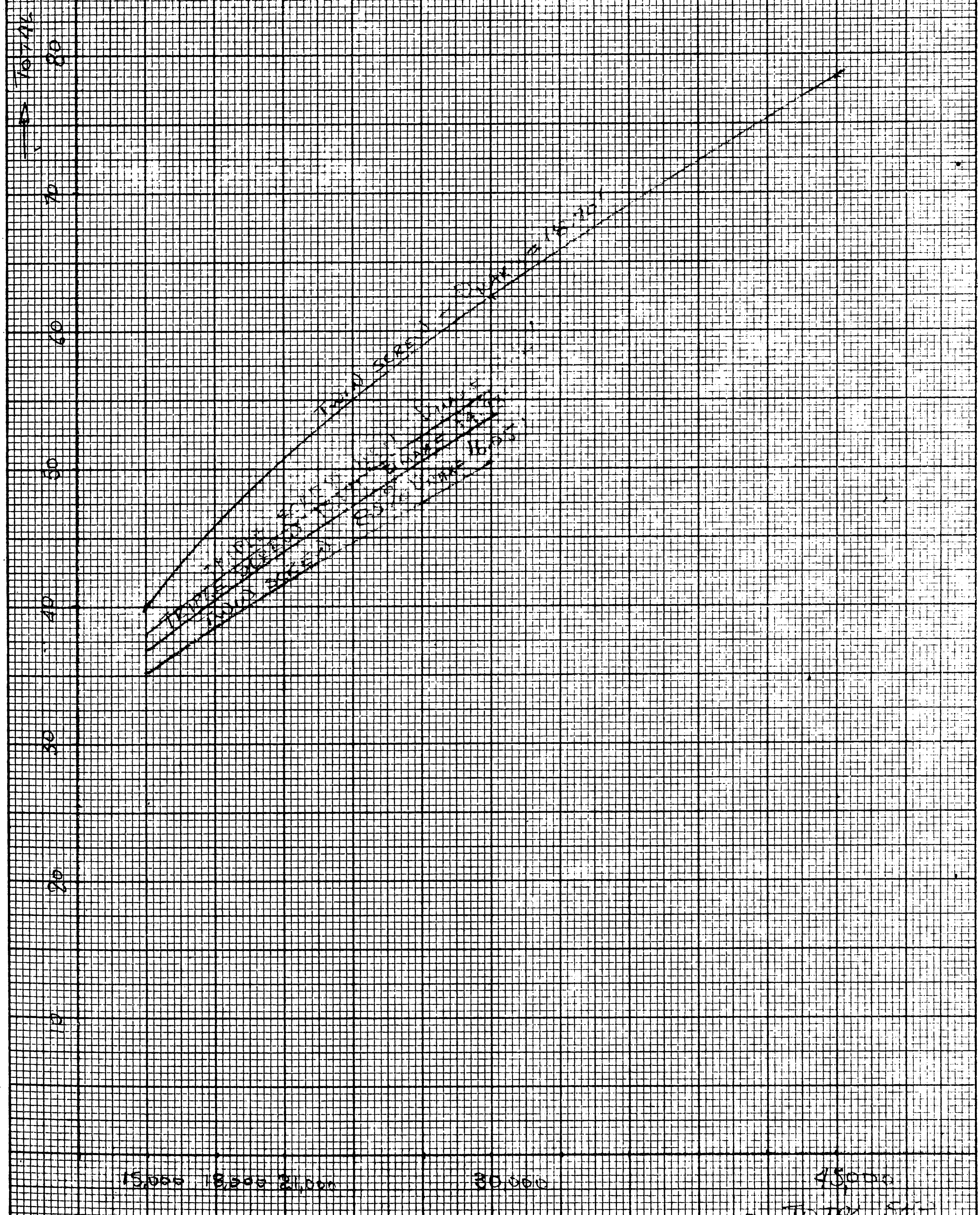
FIG 29
TOTAL THRUST VS. TOTAL SHP - AHEAD
FOR B A.70 PROPELLER
AT 120 RPM
CASE III
D_1 = MAX. DIA
D_2 = 0.85 D_1
D_3 = 0.70 D_1
(AVERAGE DIA.)
T_{TOTAL}
10^4 LBS
90
80
70
60
50
40
30
20
10
0
15,000
30000
45000
60000
SHP_{TOTAL}
TWIN SCREW
TRIPLE SCREW (1:1:1)
D_1 = 20.88 FT
D_1 = 21.6/15.3 FT
D_1 = 17.4 FT
D_2 = 17.8 FT
D_2 = 14.8 FT
D_2 = 14.4/13 FT
D_3 = 14.65 FT
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:3:1)
Limit for comparison (Burrill cavitation limit)
(31,500)

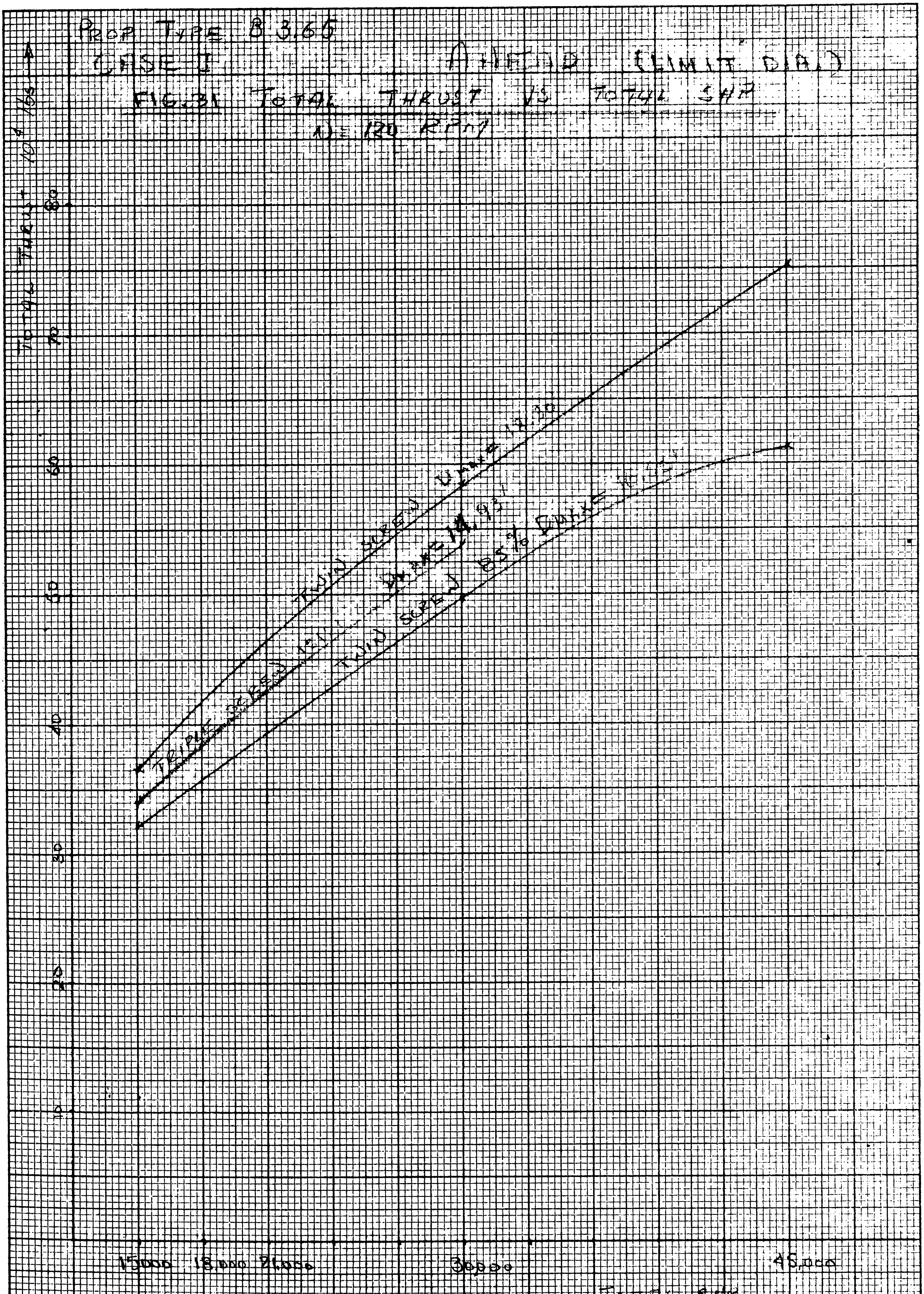
CASE II

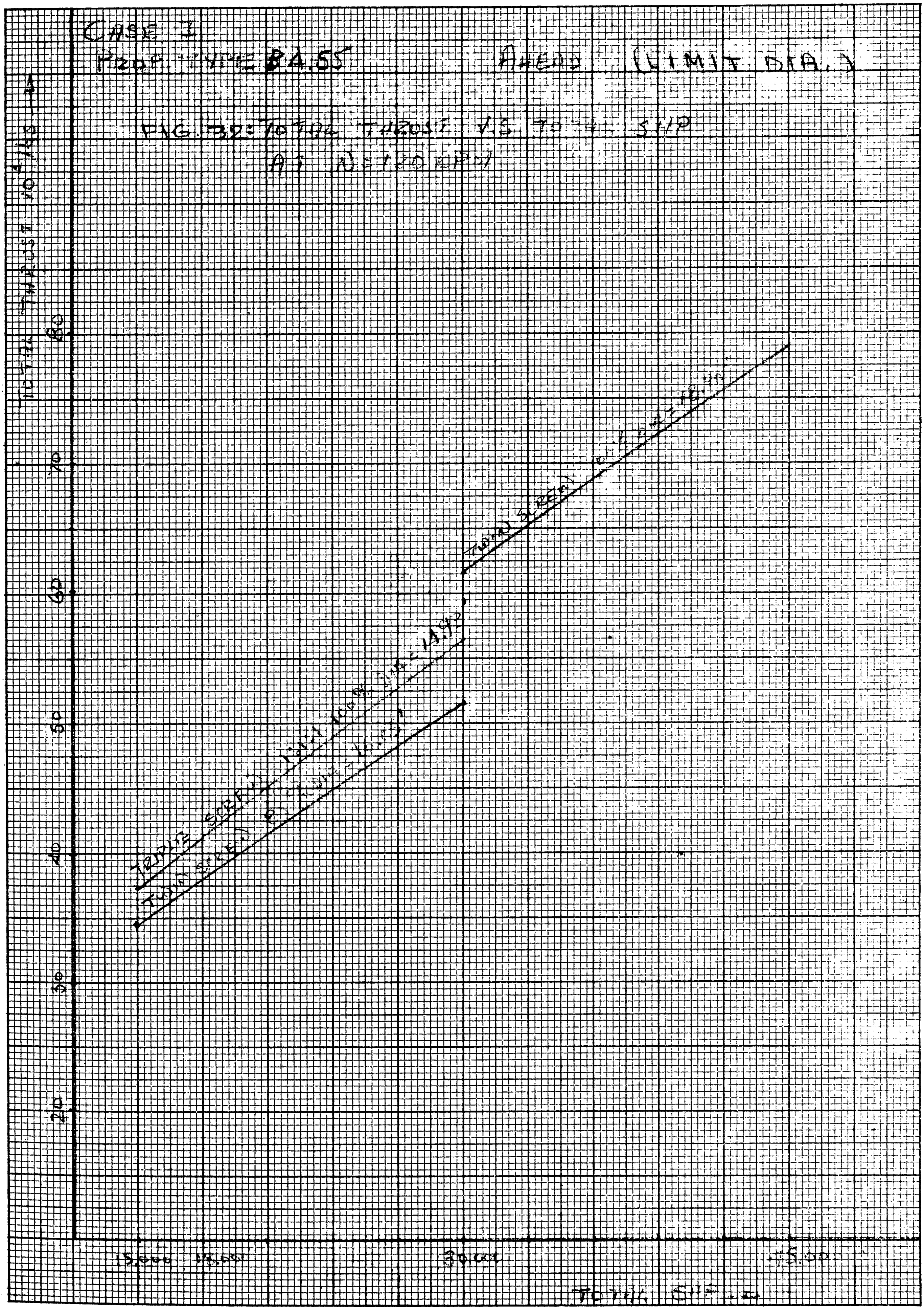
FIG. 30 TOTAL THRUST VS TOTAL SHP - AHEAD

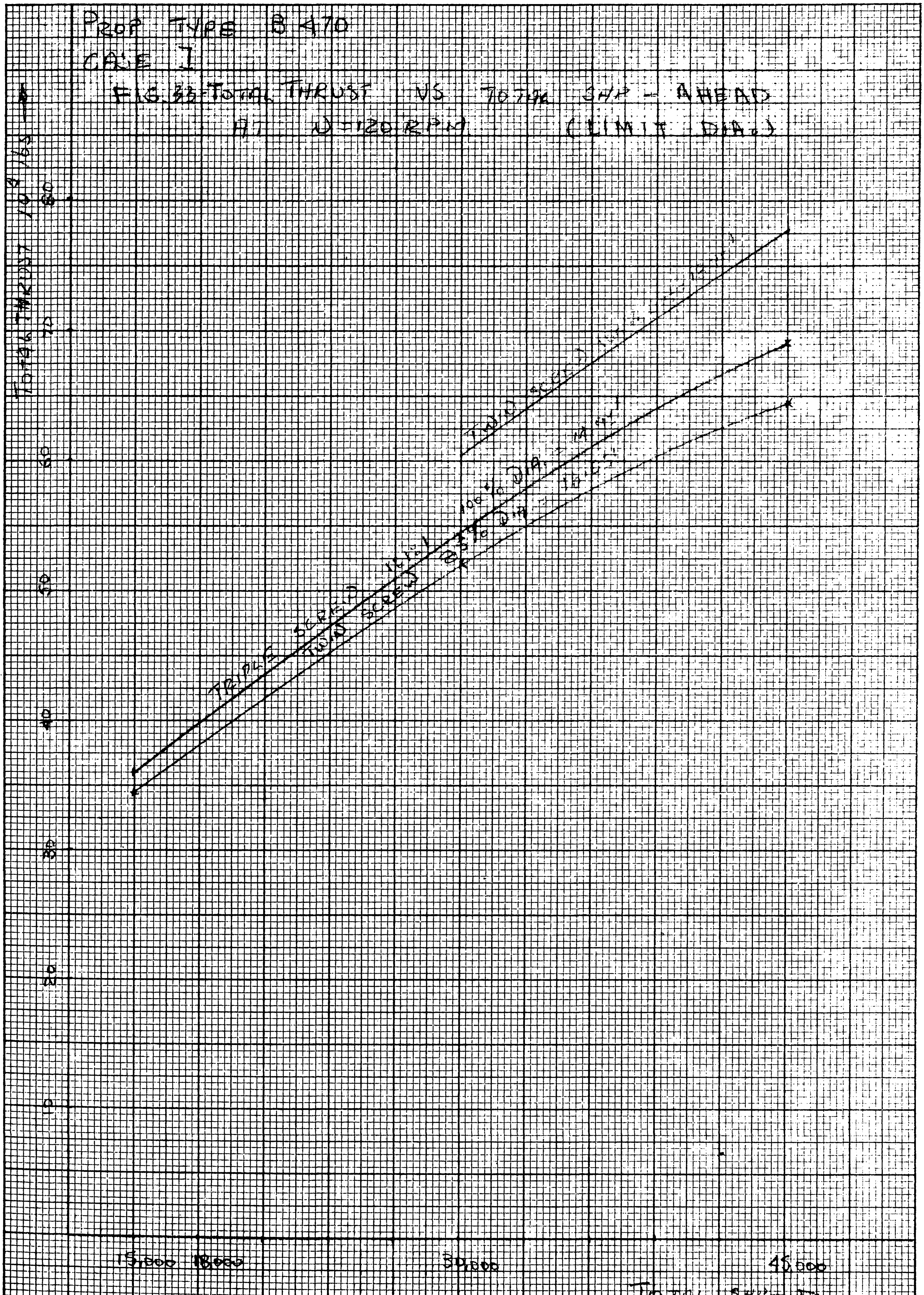
FOR B-3.50 PROPELLER AT 120 RPM

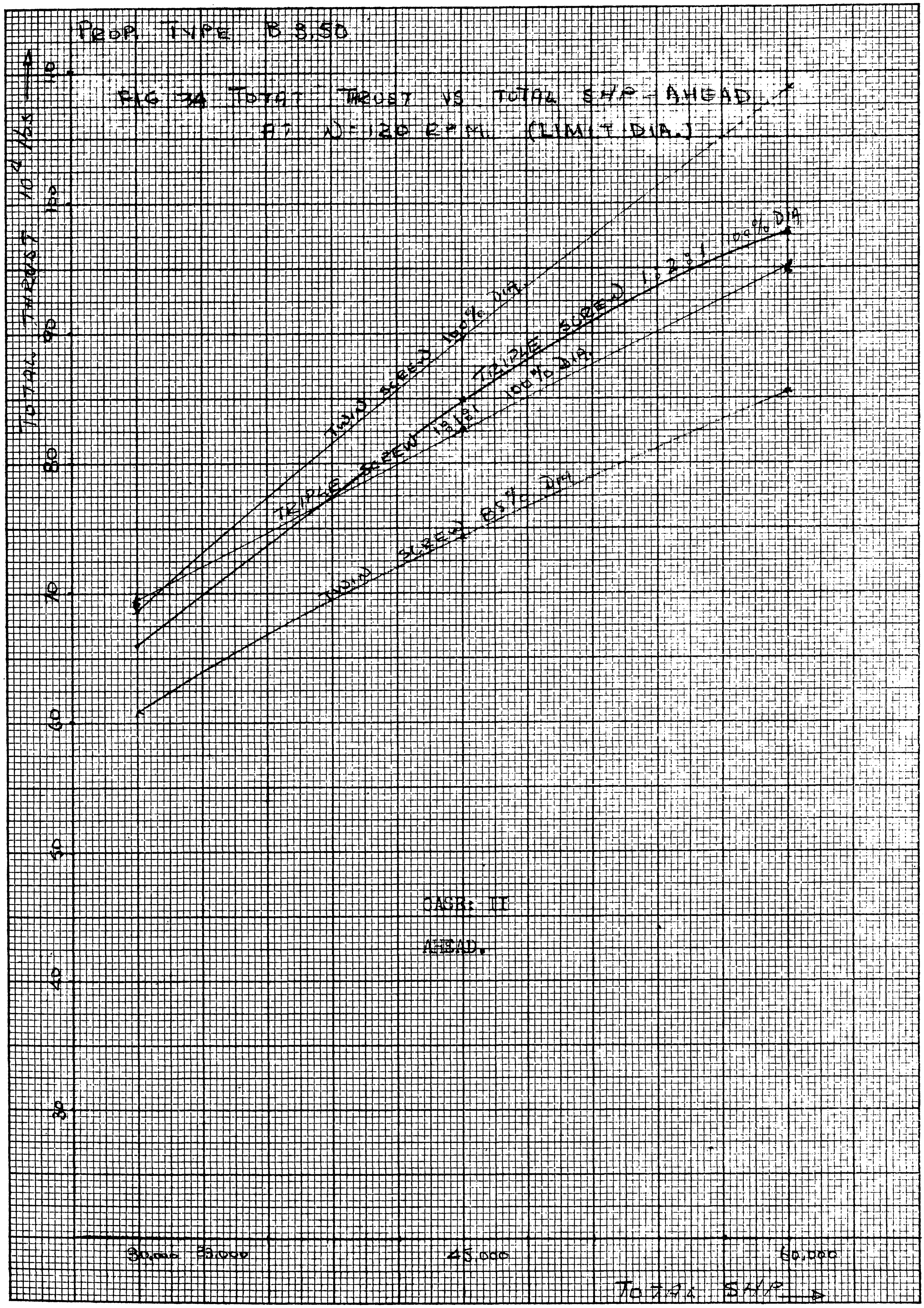
(LIMIT - DIA.)




PROP TYPE B 3.65
CASE II
AHEAD (LIMIT DIA)
FIG. 31 TOTAL THRUST VS TOTAL SHP
N = 124 RPM
TOTAL THRUST 10^4 lbs
80
70
60
50
40
30
20
10
TWIN SCREW
TRIPLE SCREW
TWIN SCREW 85%
15000
18,000
21,000
30000
45,000
TOTAL SHP


CASE I
PROP TYPE B4.55
AHEAD (LIMIT DIA.)
FIG. 32: TOTAL THRUST VS TOTAL SHP
TOTAL THRUST
80
70
60
50
40
30
20
15,000
30,000
45,000
TOTAL SHP


PROP TYPE B 470
CASE I
FIG. 33 TOTAL THRUST VS TOTAL SHP - AHEAD
AT N=120 RPM (LIMIT DIA.)
TOTAL THRUST 10^4 lbs
80
70
60
50
40
30
20
10
TWIN SCREW
TRIPLE SCREW
TWIN SCREW
100 % DIA.
85 % DIA.
15,000
18000
30,000
45,000
TOTAL SHP



PROP. TYPE B 3.50
FIG 34 TOTAL THRUST VS TOTAL SHP - AHEAD
AT N=120 RPM (LIMIT DIA.)
110
100
90
80
70
60
50
40
30
TWIN SCREW 100% DIA
TRIPLE SCREW 1:2:1
100% DIA
TRIPLE SCREW
100% DIA
TWIN SCREW 85% DIA
CASE: II
AHEAD.
30,000
35,000
45,000
60,000
TOTAL SHP

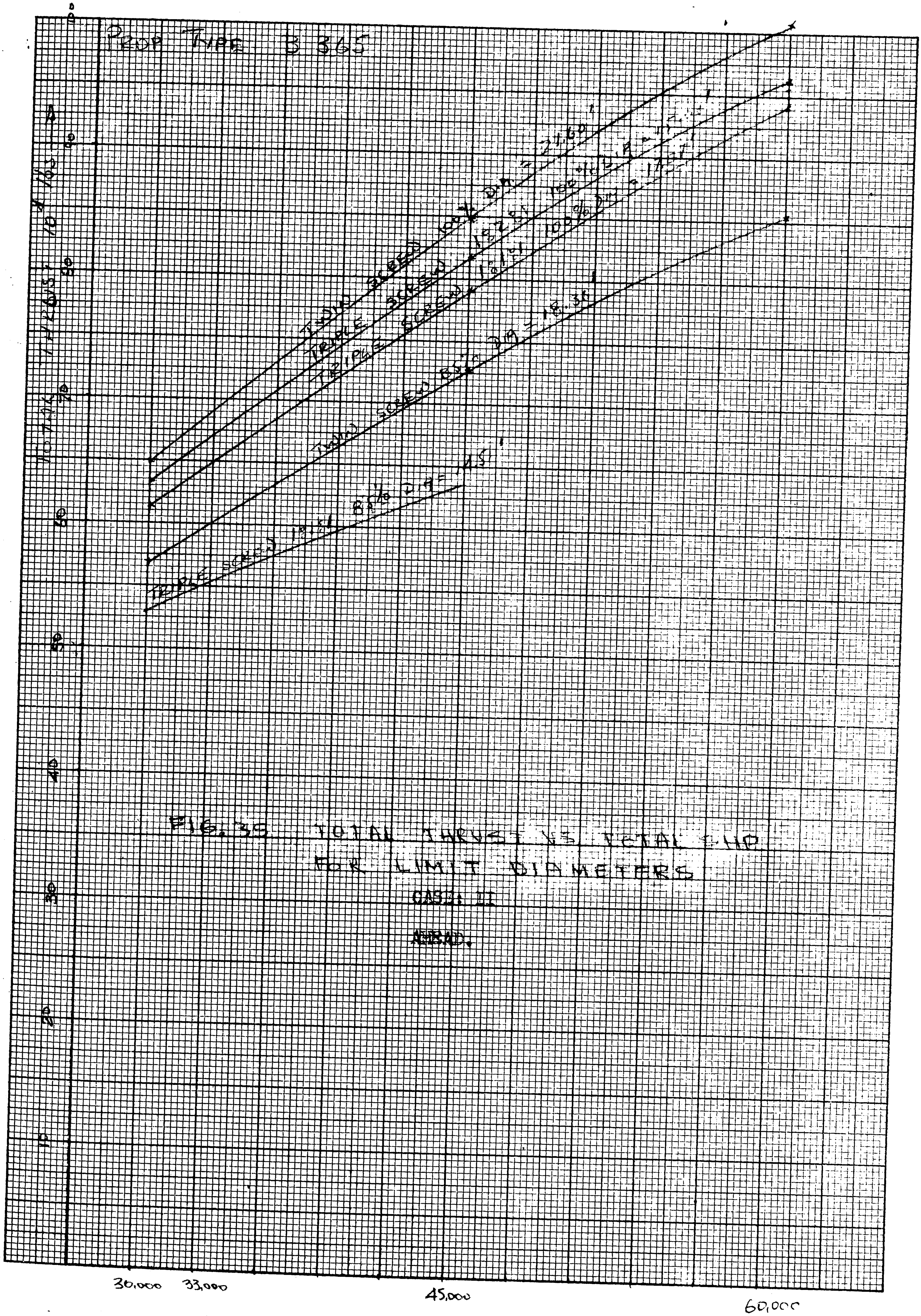


FIG. 35 TOTAL THRUST VS TOTAL SHP FOR LIMIT DIAMETERS

CASE: II

AHEAD.

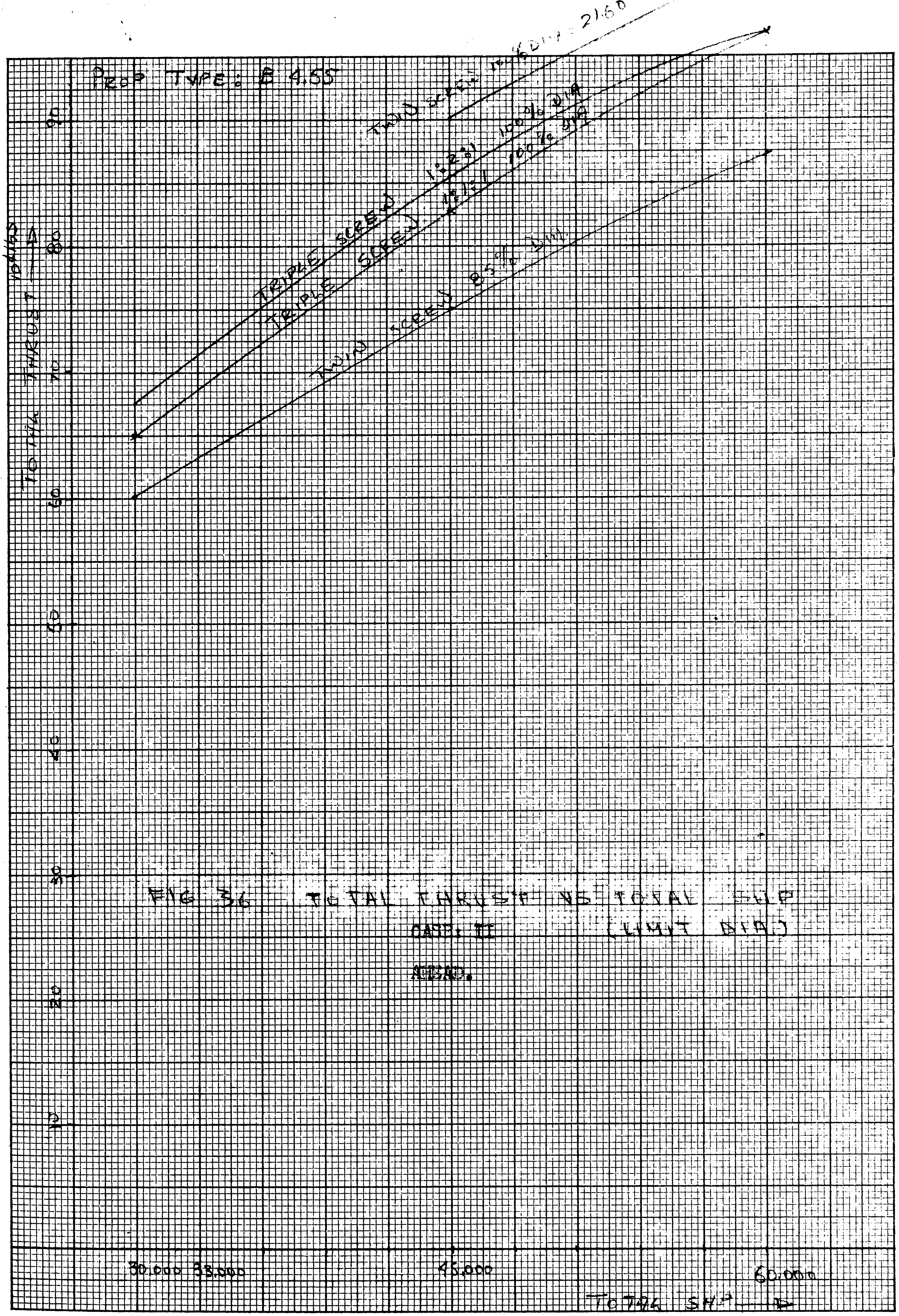
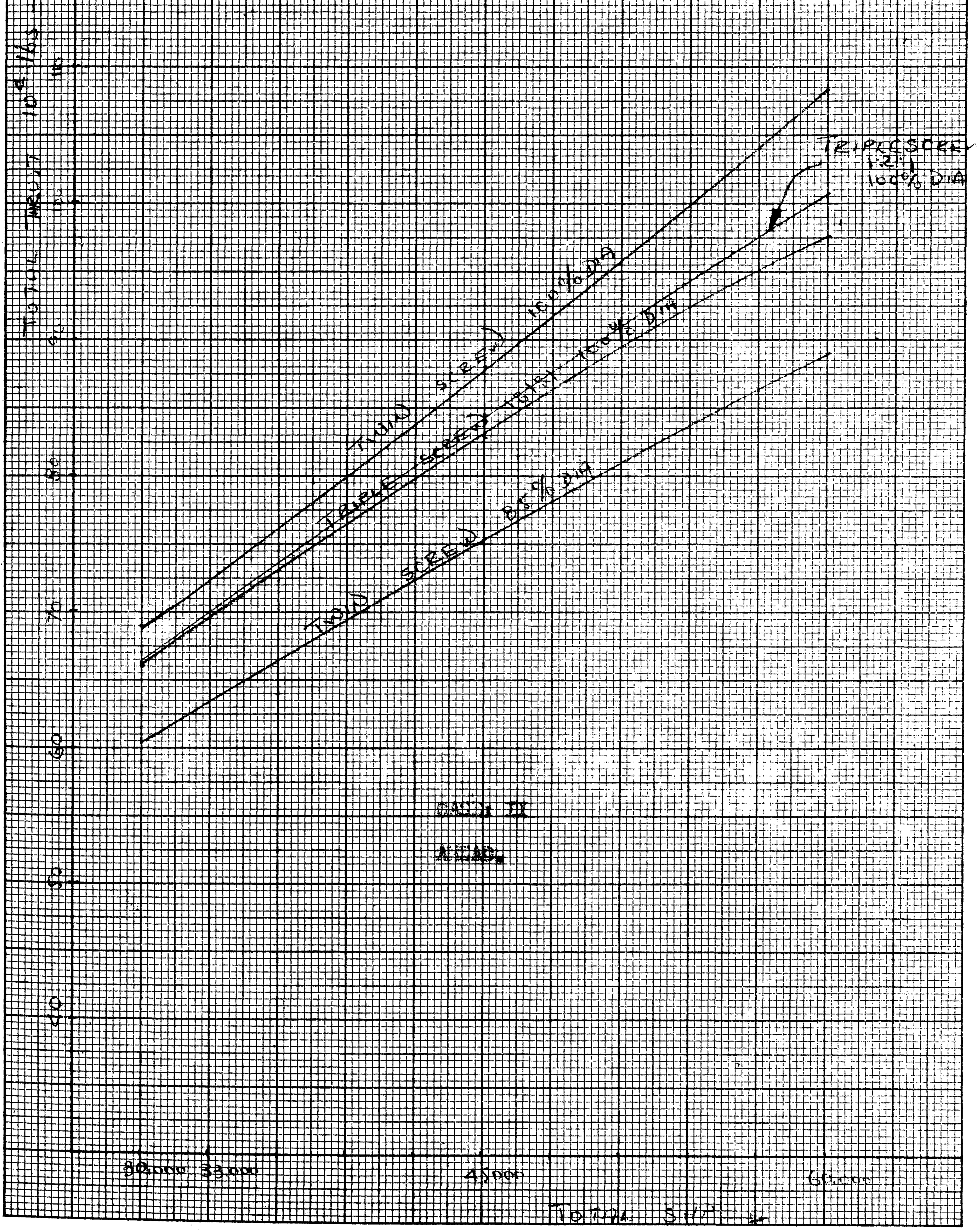
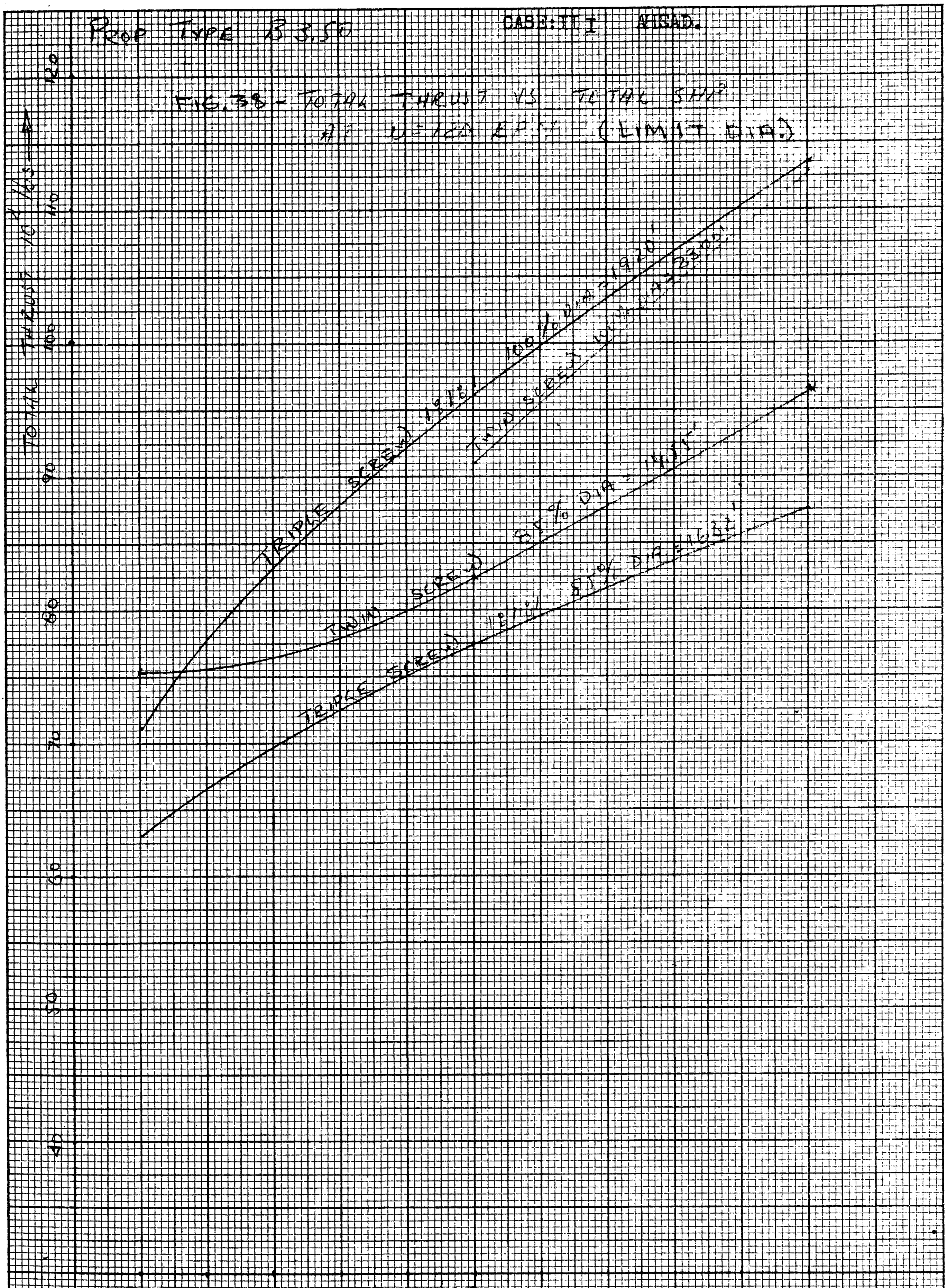


FIG 36 TOTAL THRUST VS TOTAL SHP
CASE: II (LIMIT DIA)
ADBAD.

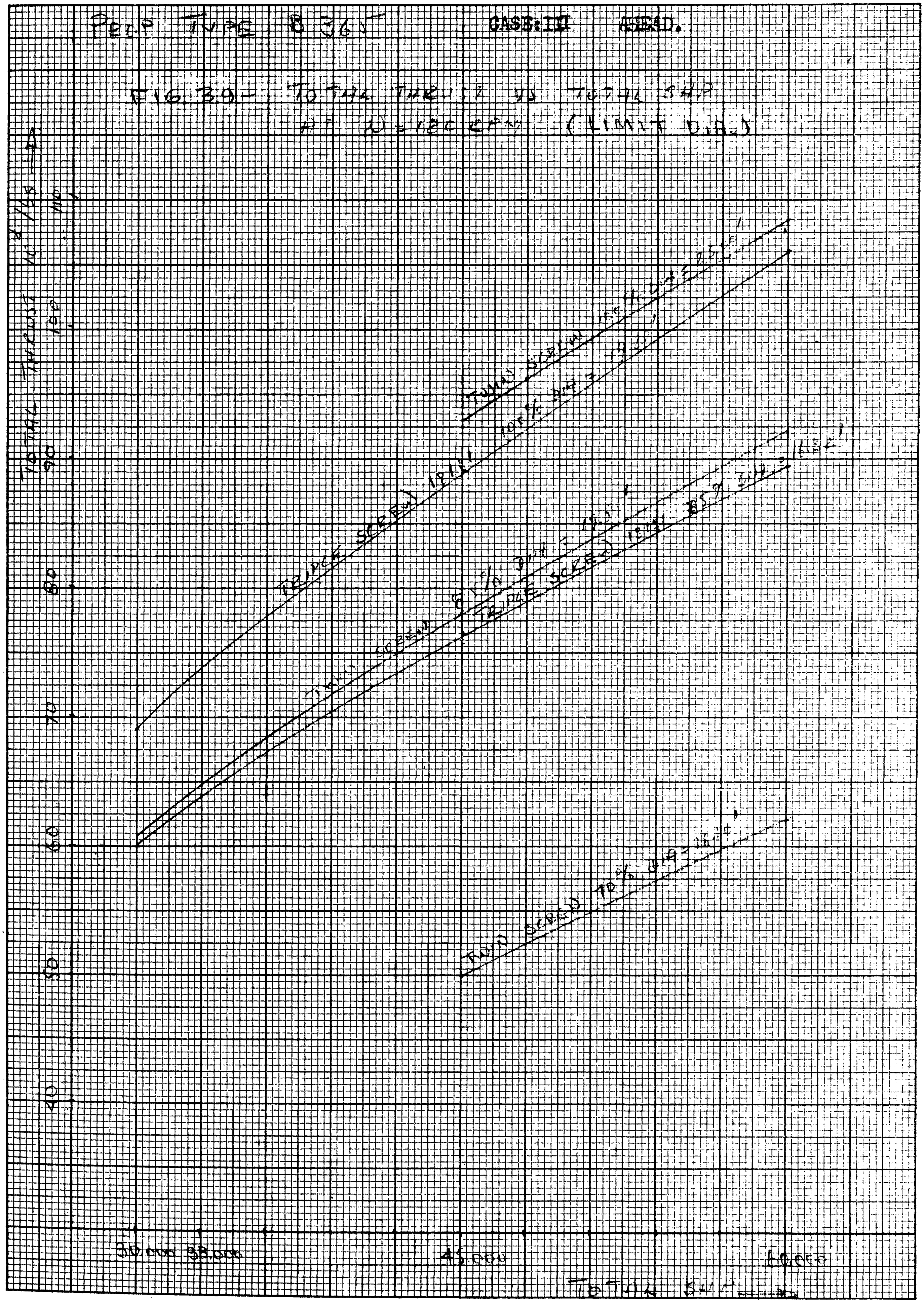
PROP TYPE B 470

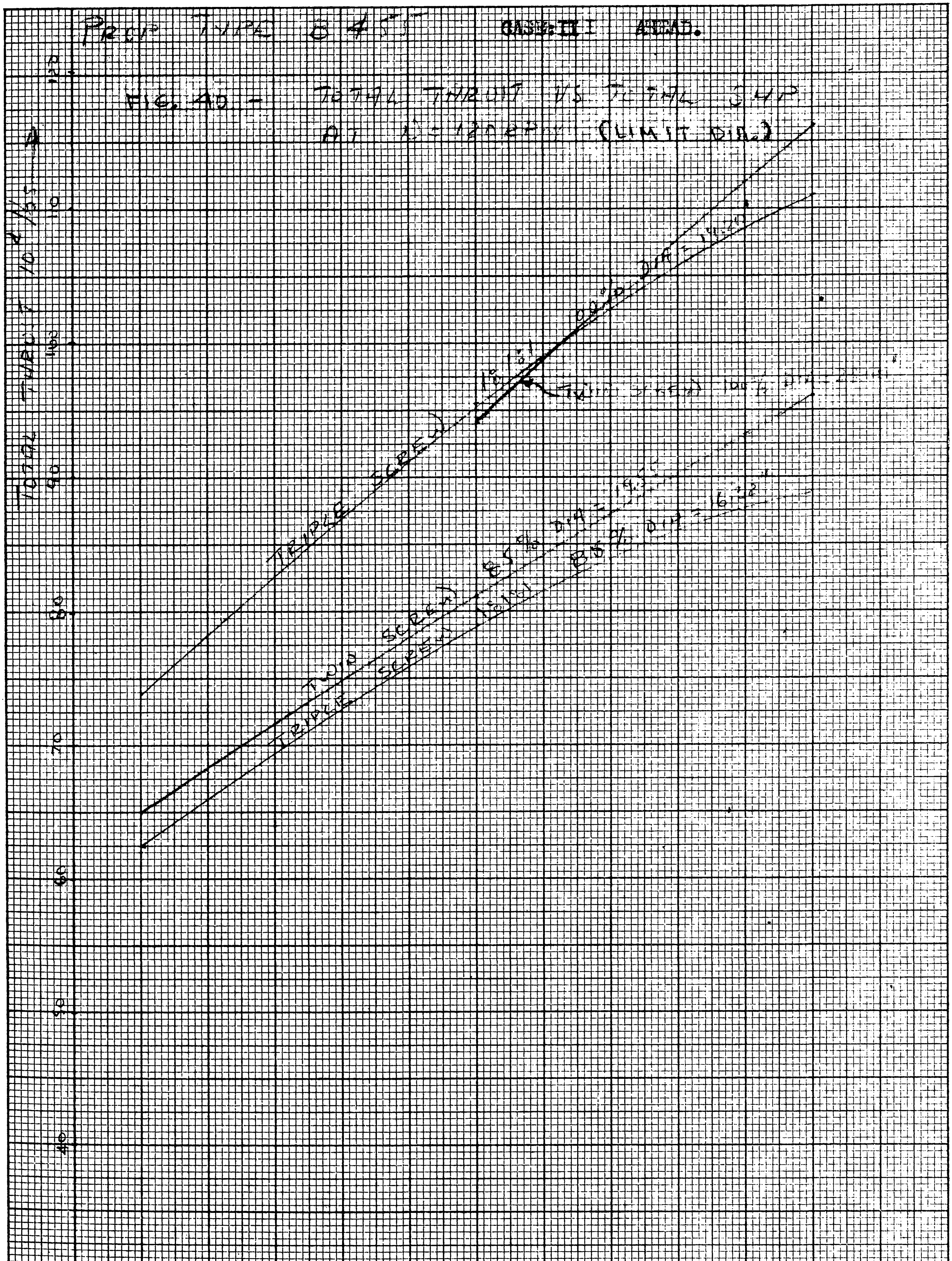
FIG. 37 TOTAL THRUST VS TOTAL SHP AT N=120 RPM (LIMIT DIA.)



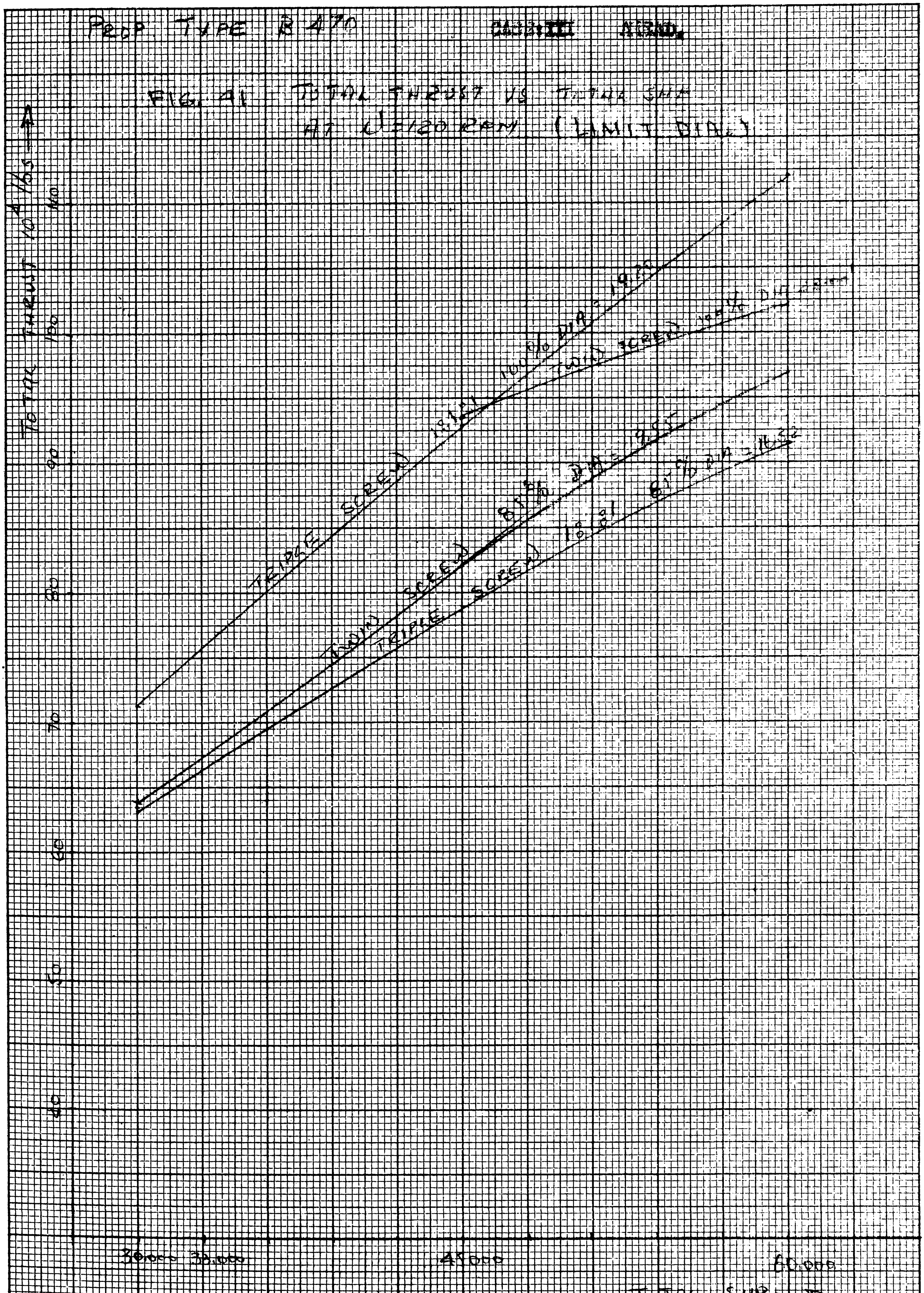


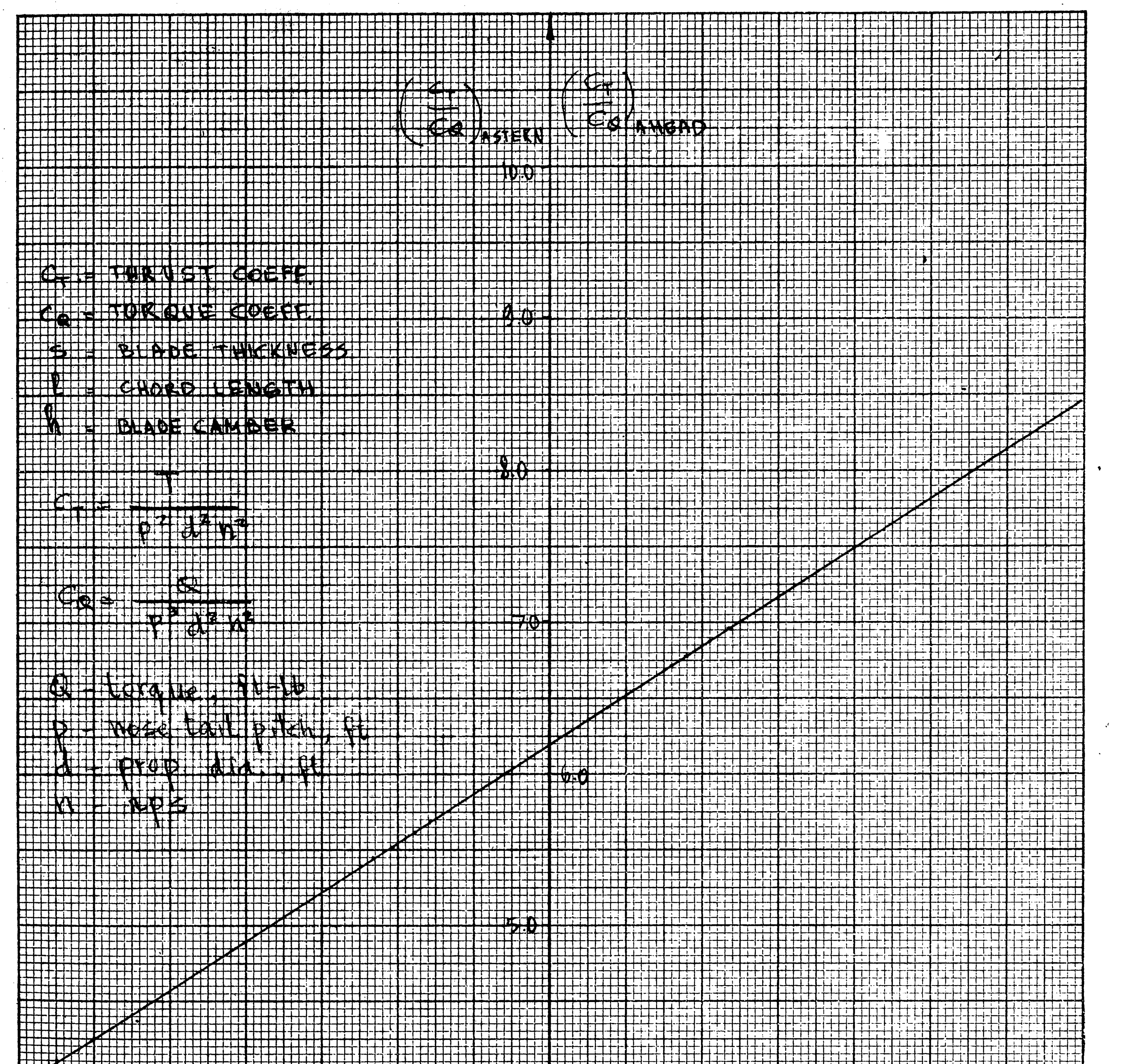
PROP TYPE B 3.50
CASE: III AHEAD.
FIG. 38 - TOTAL THRUST VS TOTAL SHP
(LIMIT DIA.)
TOTAL THRUST
120
110
100
90
80
70
60
50
40
TRIPLE SCREW
100% DIA
TWIN SCREW
TWIN SCREW
85% DIA
TRIPLE SCREW
85% DIA
30,000
33,000
45,000
60,000
TOTAL SHP


PERP TYPE B 36
CASE: III
AHEAD.
FIG. 39 – TOTAL THRUST VS TOTAL SHP
(LIMIT D.A.)
TOTAL THRUST
100
90
80
70
60
50
40
TWIN SCREW
100% D.A.
TRIPLE SCREW
TWIN SCREW
TRIPLE SCREW
TWIN SCREW 70% D.A.
45,000
60,000
TOTAL SHP



PROP TYPE B 4.55
CASE: III AHEAD.
FIG. 40 - TOTAL THRUST VS TOTAL SHP
(LIMIT DIA.)
TOTAL THRUST
TRIPLE SCREW
TWIN SCREW
TRIPLE SCREW
85% DIA
85% DIA
30,000
35,000
45000
60
TOTAL SHP


PROP TYPE B 4.70
FIG. 41 TOTAL THRUST VS TOTAL SHP
AT N=120 RPM (LIMIT DIA.)
TOTAL THRUST 10^4 lbs
TRIPLE SCREW 19.1'
100% DIA = 19.75
TWIN SCREW 100% DIA
TWIN SCREW 81% DIA = 19.35
TRIPLE SCREW 16.01' 81% DIA = 16.52
30,000 35,000 45,000 60,000
TOTAL SHP

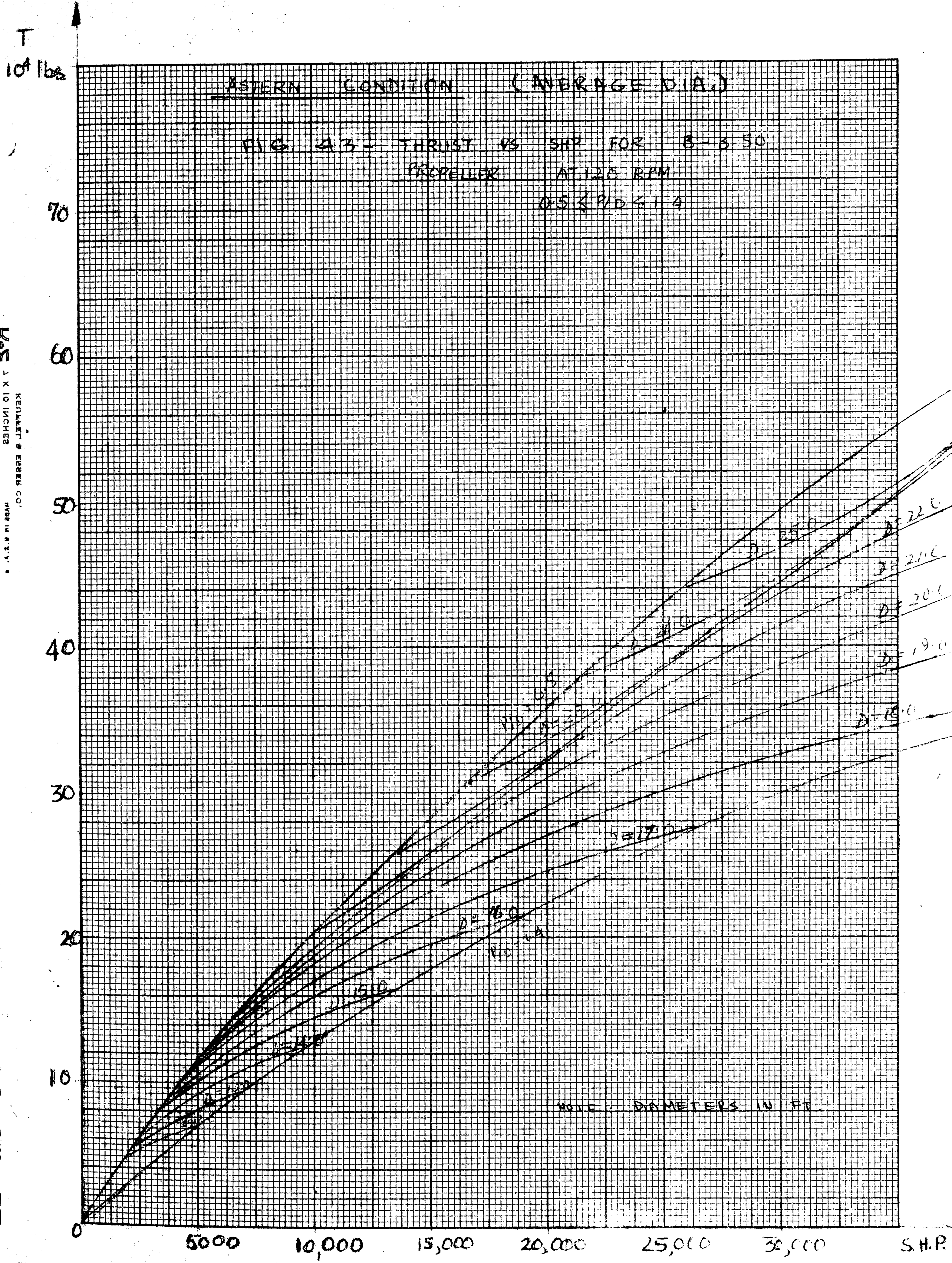


ASTERN ROTATION OF PROPELLER — AHEAD ROTATION OF PROPELLER

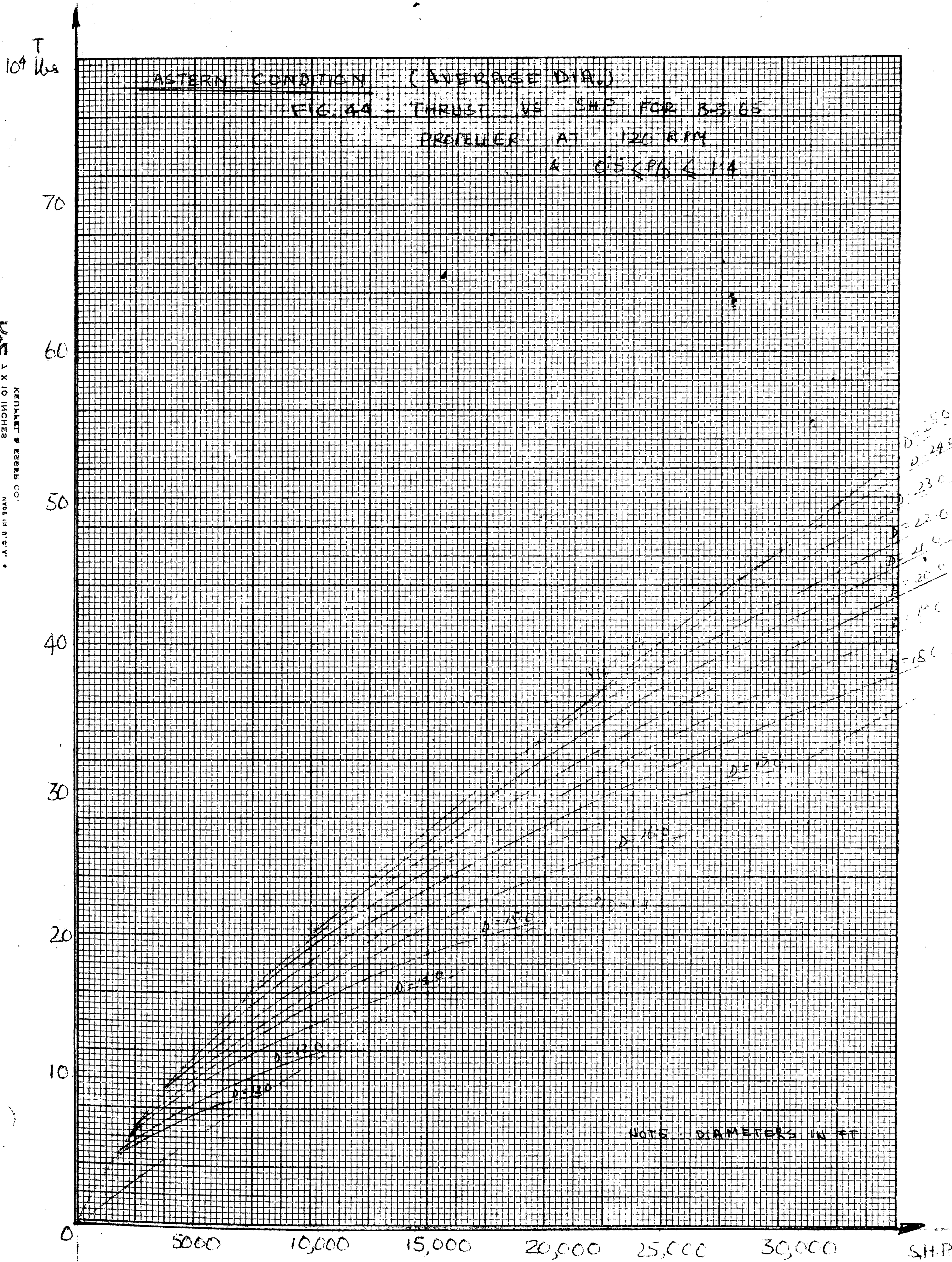
FIG. 42

THRUST - TORQUE COEFFICIENT vs. BLADE CAMBER RATIO FOR AHEAD AND ASTERN PROPELLER ROTATION

Reference: Average of curves in Fig 27, SNAME Bulletin No 3-5 "Guide to the Selection of Backing Power" edited by A.M. D'Archangelo

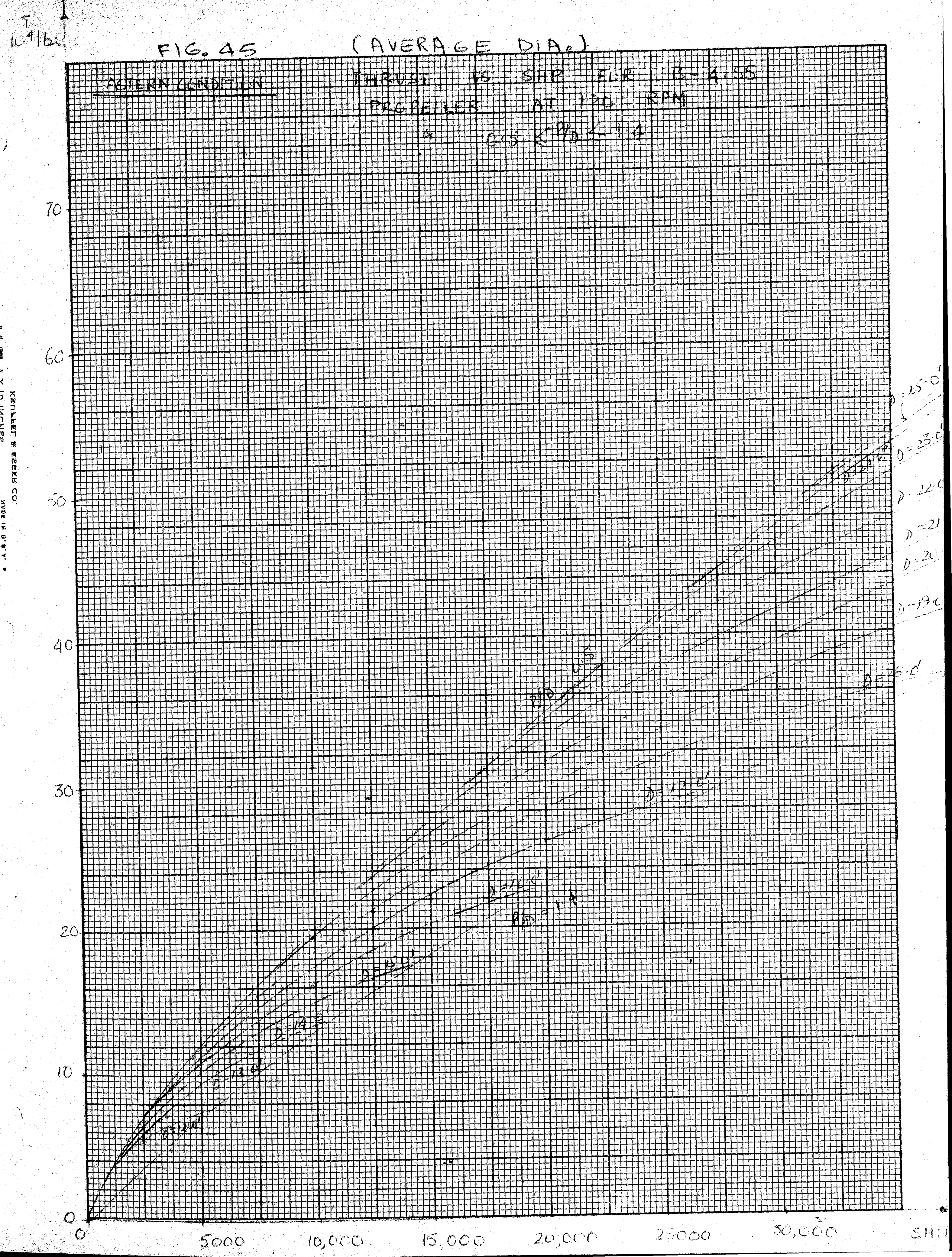


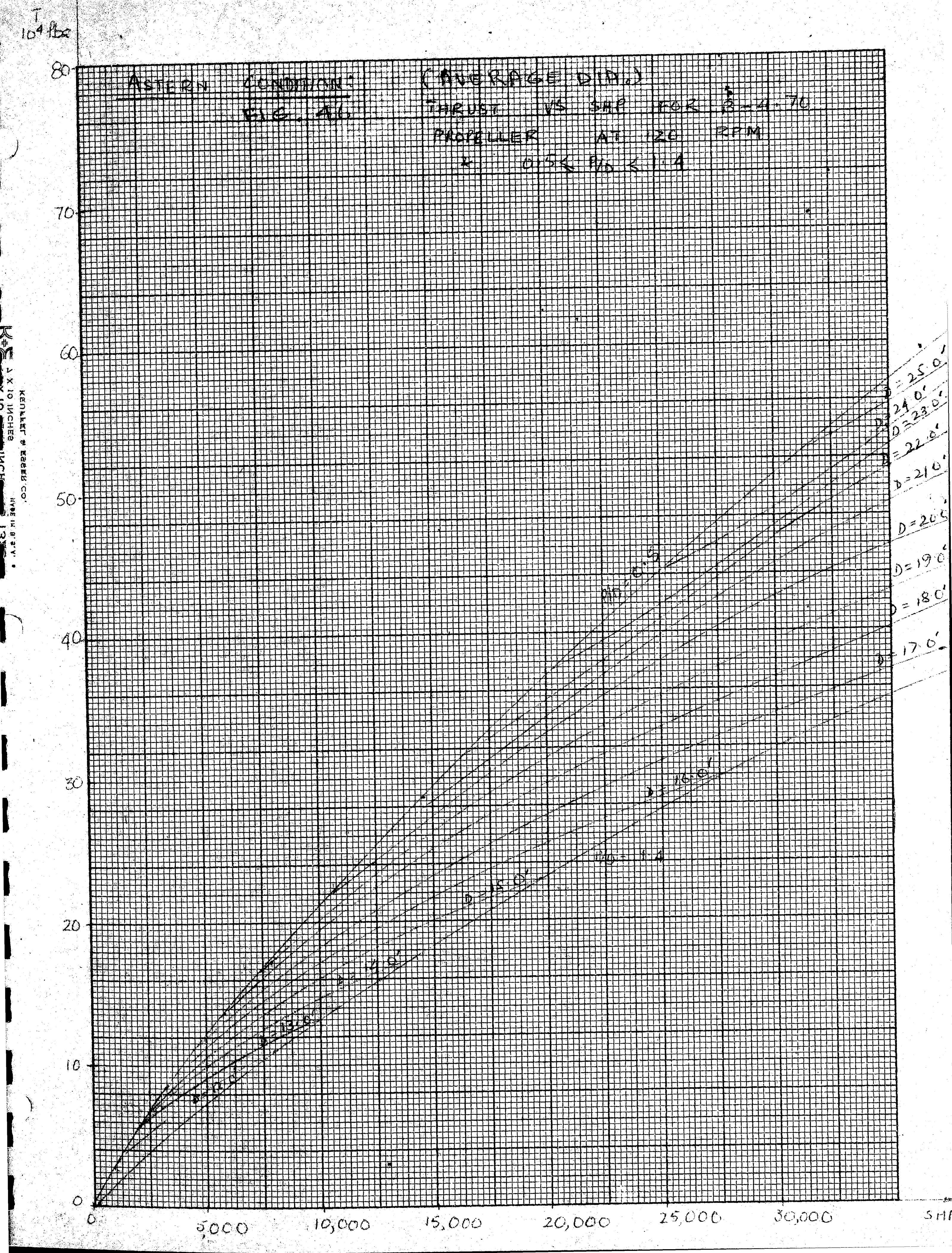
ASTERN CONDITION (AVERAGE DIA.)
FIG. 43 - THRUST VS SHP FOR B-3.50 PROPELLER AT 128 RPM
0.5 ≤ P/D ≤ 1.4
T
10⁴ lbs
70
60
50
40
30
20
10
0
5000
10,000
15,000
20,000
25,000
30,000
S.H.P.
D=25.0
D=24.0
D=22.0
D=21.0
D=20.0
D=19.0
D=18.0
D=17.0
D=16.0
D=15.0
D=14.0
NOTE: DIAMETERS IN FT

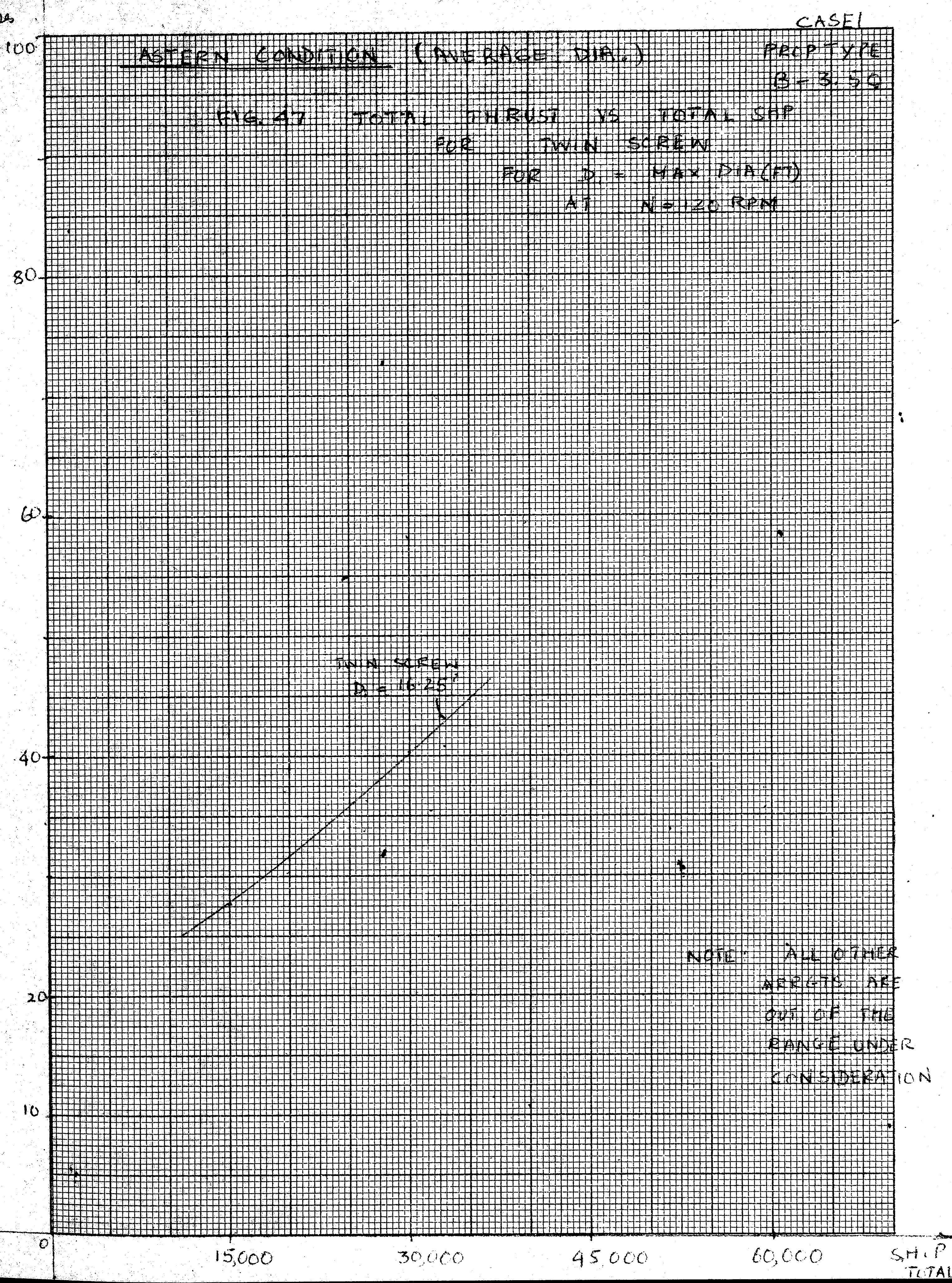


ASTERN CONDITION (AVERAGE DIA.)
FIG. 44 - THRUST VS SHP FOR B-3.65
PROPELLER AT 120 RPM
& 0.5 ≤ P/D ≤ 1.4
NOTE: DIAMETERS IN FT
T
10⁴ lbs
70
60
50
40
30
20
10
0
5000
10,000
15,000
20,000
25,000
30,000
SHP

FIG. 45 (AVERAGE DIA.)

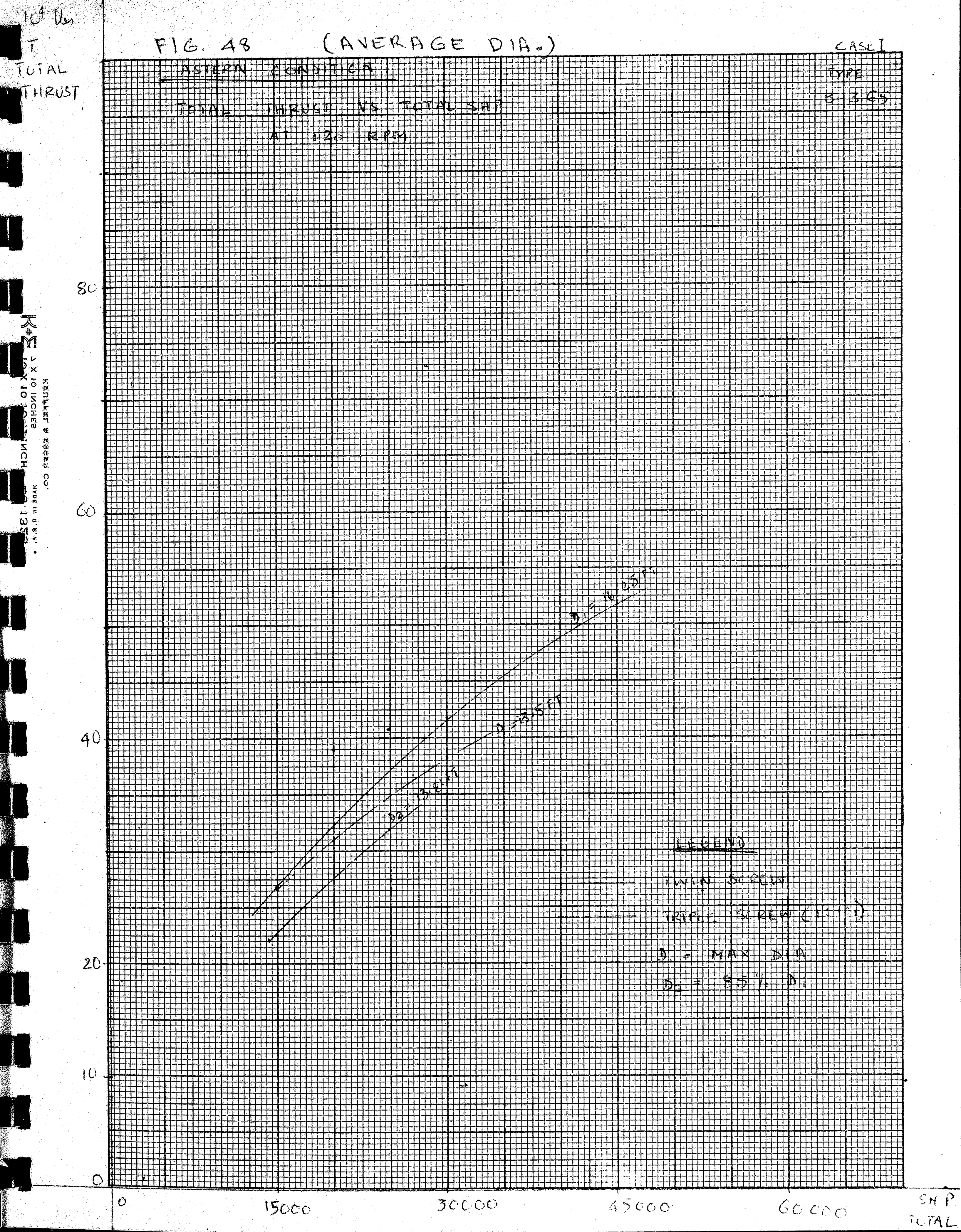


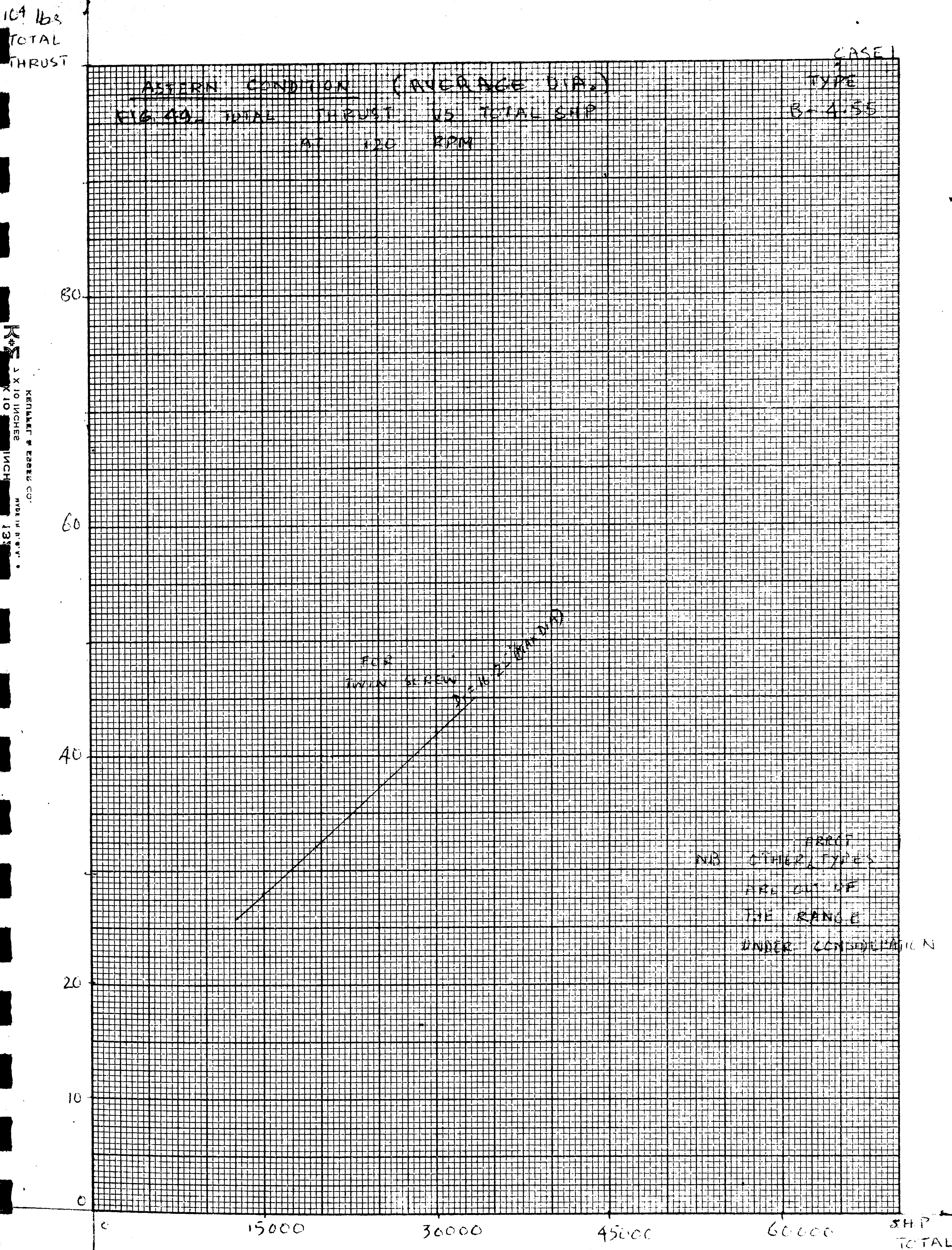

ASTERN CONDITION: (AVERAGE DIA.)
FIG. A6
THRUST VS SHP FOR B-4-70
PROPELLER AT 120 RPM
& 0.5 ≤ P/D ≤ 1.4
T 10^4 lbs
80
70
60
50
40
30
20
10
0
0
5,000
10,000
15,000
20,000
25,000
30,000
SHP
D = 25.0'
D = 24.0'
D = 23.0'
D = 22.0'
D = 21.0'
D = 20.0'
D = 19.0'
D = 18.0'
D = 17.0'
D = 16.0'
D = 15.0'
D = 14.0'
D = 13.0'
D = 12.0'
P/D = 0.5
P/D = 1.4
KEUFFEL & ESSER CO.
10 X 10 TO THE INCH
7 X 10 INCHES
MADE IN U.S.A.

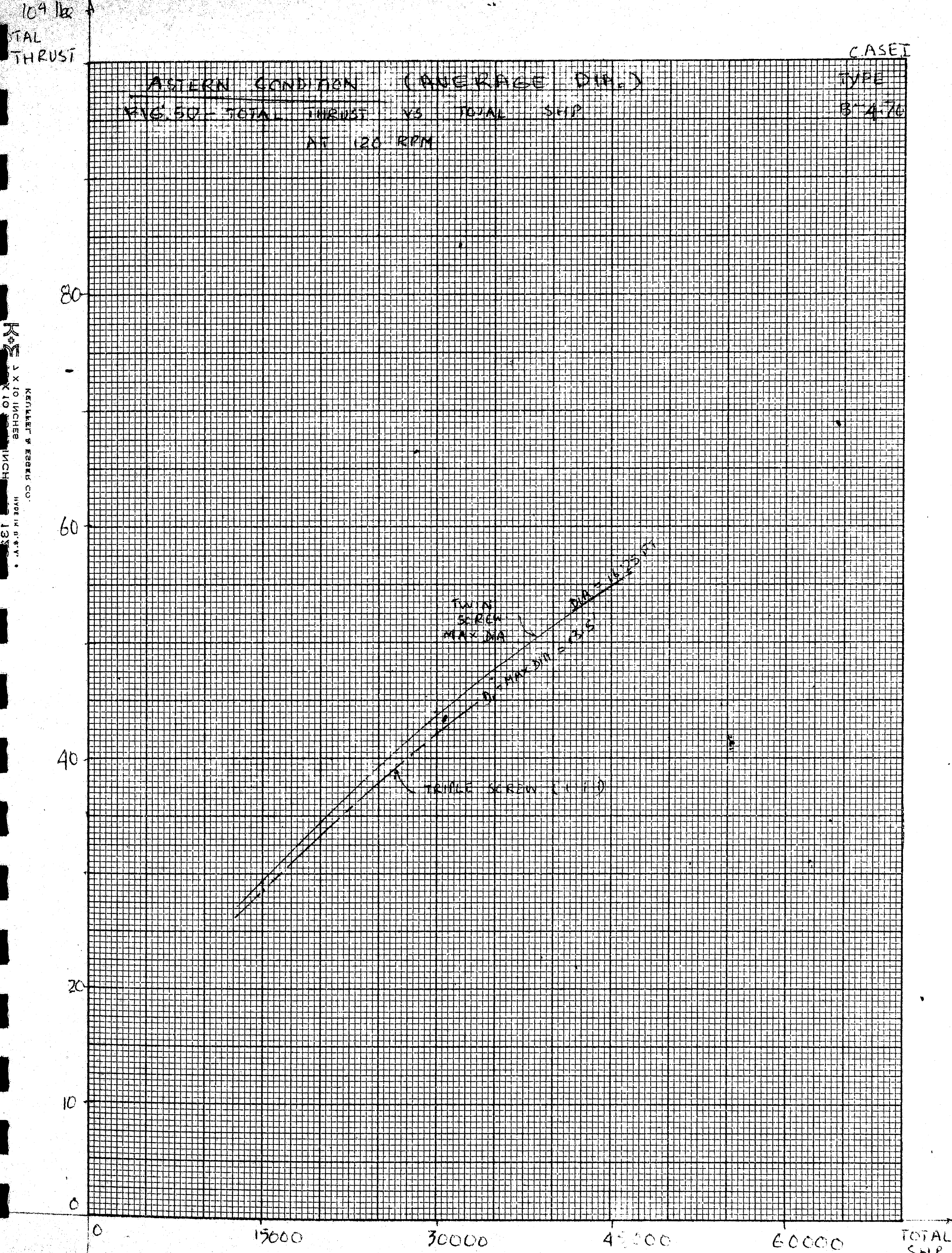


CASE I
ASTERN CONDITION (AVERAGE DIA.)
PROP TYPE B-3.50
FIG. 47 TOTAL THRUST VS TOTAL SHP
FOR TWIN SCREW
FOR D = MAX DIA (FT)
AT N = 120 RPM
T 10^4 lbs
100
80
60
40
20
10
0
15,000
30,000
45,000
60,000
SHP TOTAL
TWIN SCREW
D = 16.25'
NOTE: ALL OTHER AERGTS ARE OUT OF THE RANGE UNDER CONSIDERATION

FIG. 48 (AVERAGE DIA.)

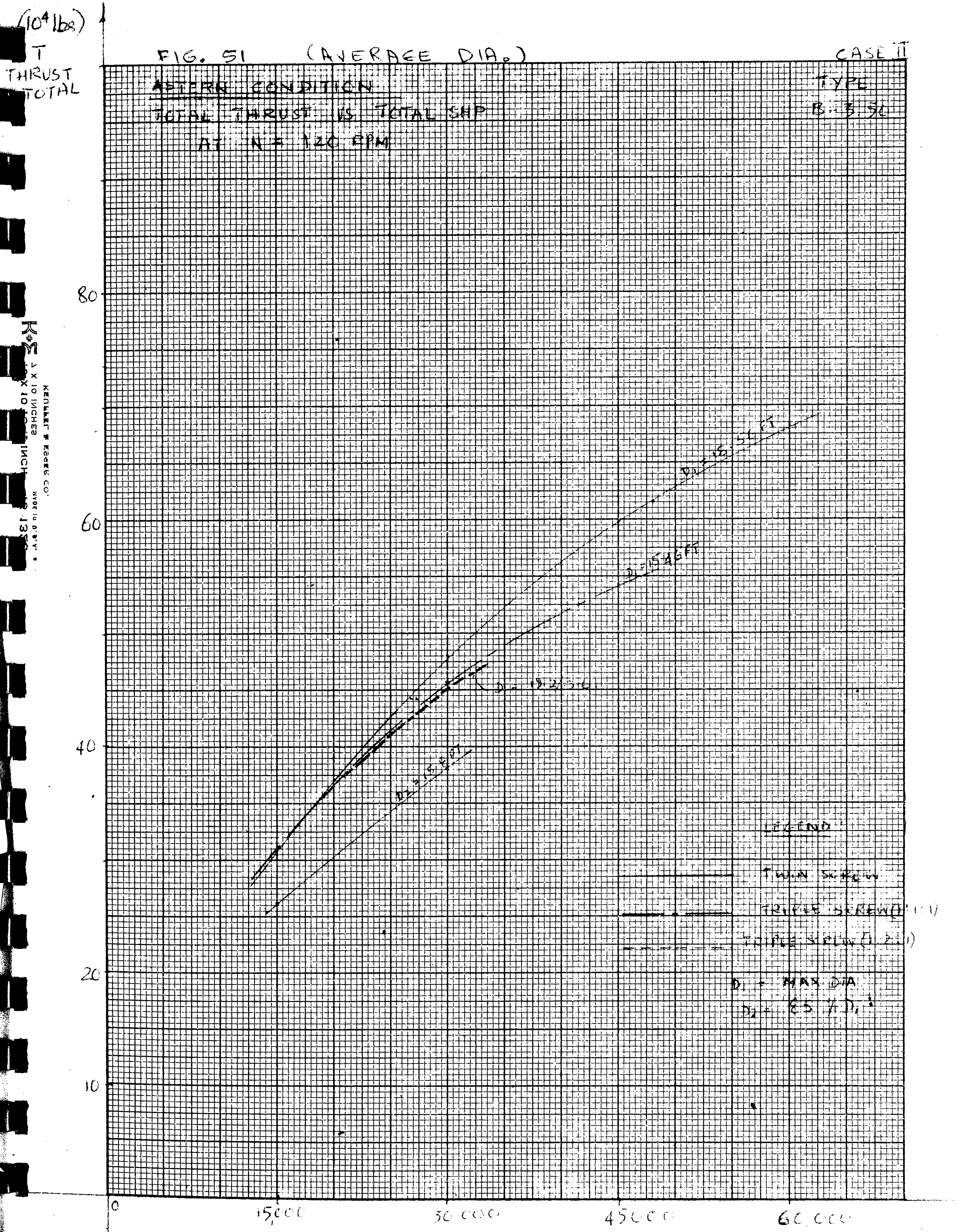



10⁴ lbs
TOTAL
THRUST
CASE I
ASTERN CONDITION (AVERAGE DIA.)
FIG. 49 - TOTAL THRUST VS TOTAL SHP
AT 120 RPM
TYPE
B-4.55
FOR
TWIN SCREW
D = 14.2' (MAX DIA)
NB OTHER TYPES ARE OUT OF THE RANGE UNDER CONSIDERATION
80
60
40
20
10
0
0
15000
30000
45000
60000
SHP
TOTAL



CASE I
TYPE
B-4.70
ASTERN CONDITION (AVERAGE DIA.)
FIG. 50 - TOTAL THRUST VS TOTAL SHP
AT 120 RPM
10^4 lbs
TOTAL THRUST
TOTAL SHP
80
60
40
20
10
0
15000
30000
60000
TWIN SCREW MAX DIA
DIA = 16.25 FT
MAX DIA = 13.5'
TRIPLE SCREW
KEUFFEL & ESSER CO.
MADE IN U.S.A.

FIG. 51 (AVERAGE DIA.) CASE II



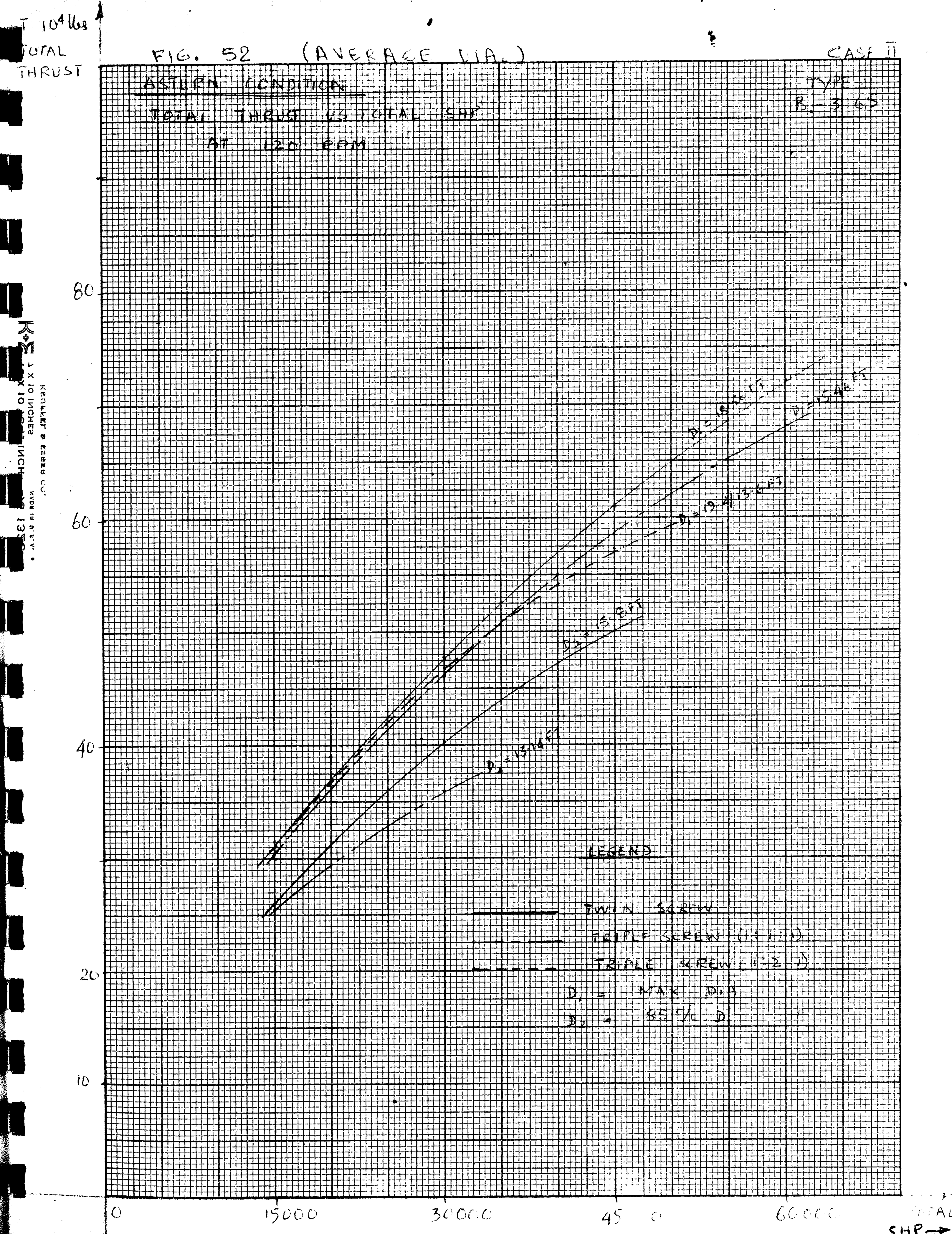
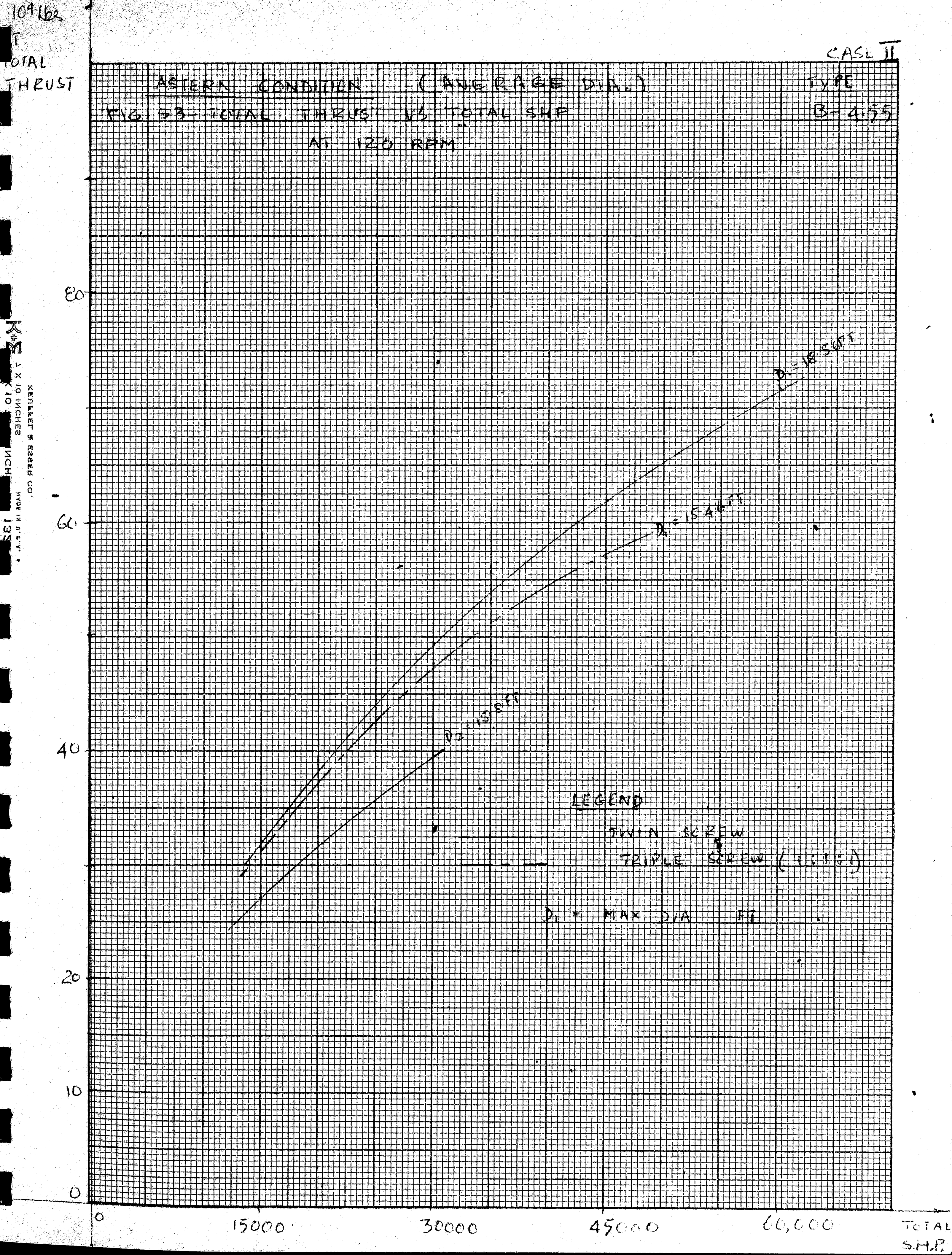


FIG. 52 (AVERAGE DIA.)
CASE II
ASTERN CONDITION
TOTAL THRUST VS TOTAL SHP
AT 120 RPM
TYPE B-3.65
T 10⁴ lbs TOTAL THRUST
80
60
40
20
10
0
15000
30000
45
60000
TOTAL SHP
LEGEND
TWIN SCREW
TRIPLE SCREW
TRIPLE SCREW
D₁ = MAX DIA
D₂ = 85% D₁
KEUFFEL & ESSER CO.



CASE II
ASTERN CONDITION (AVERAGE DIA.)
FIG. 53 - TOTAL THRUST VS TOTAL SHP
AT 120 RPM
TYPE
B-4.55
10^4 lbs
T
TOTAL
THRUST
80
60
40
20
10
0
15000
30000
45000
60,000
TOTAL
S.H.P.
D_1 = 18.5 FT
D_1 = 15.46 FT
D_1 = 13.8 FT
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
D_1 = MAX DIA FT

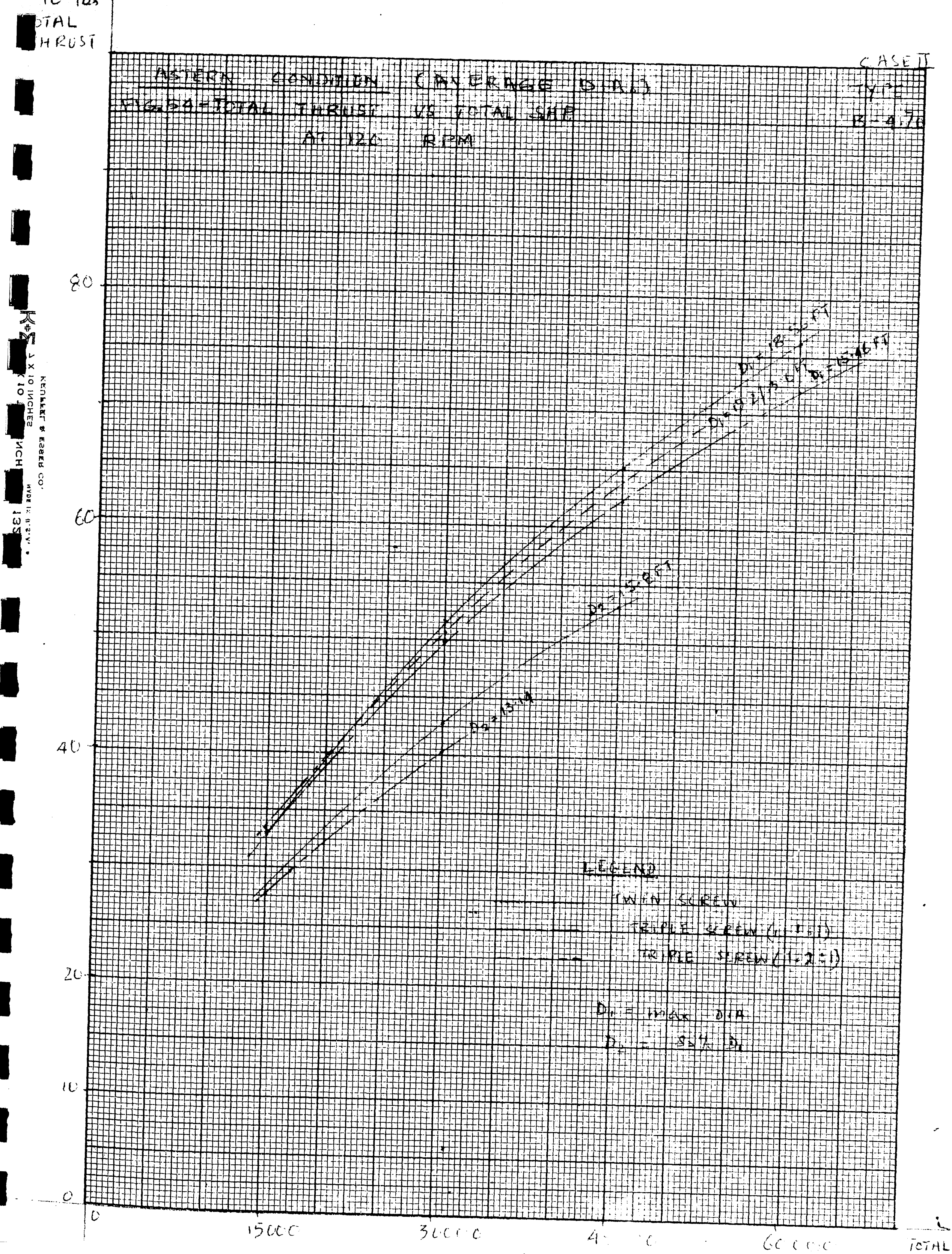

ASTERN CONDITION (AVERAGE DIA.)
FIG. 54 - TOTAL THRUST VS TOTAL SHP
AT 120 RPM
CASE II
TYPE
B-4.70
TOTAL
THRUST
80
60
40
20
10
0
0
15000
30000
60000
TOTAL
D1 = 18.5 FT
D2 = 15.8 FT
D2 = 13.14
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D1 = MAX DIA
D2 = 85% D1

FIG. 55

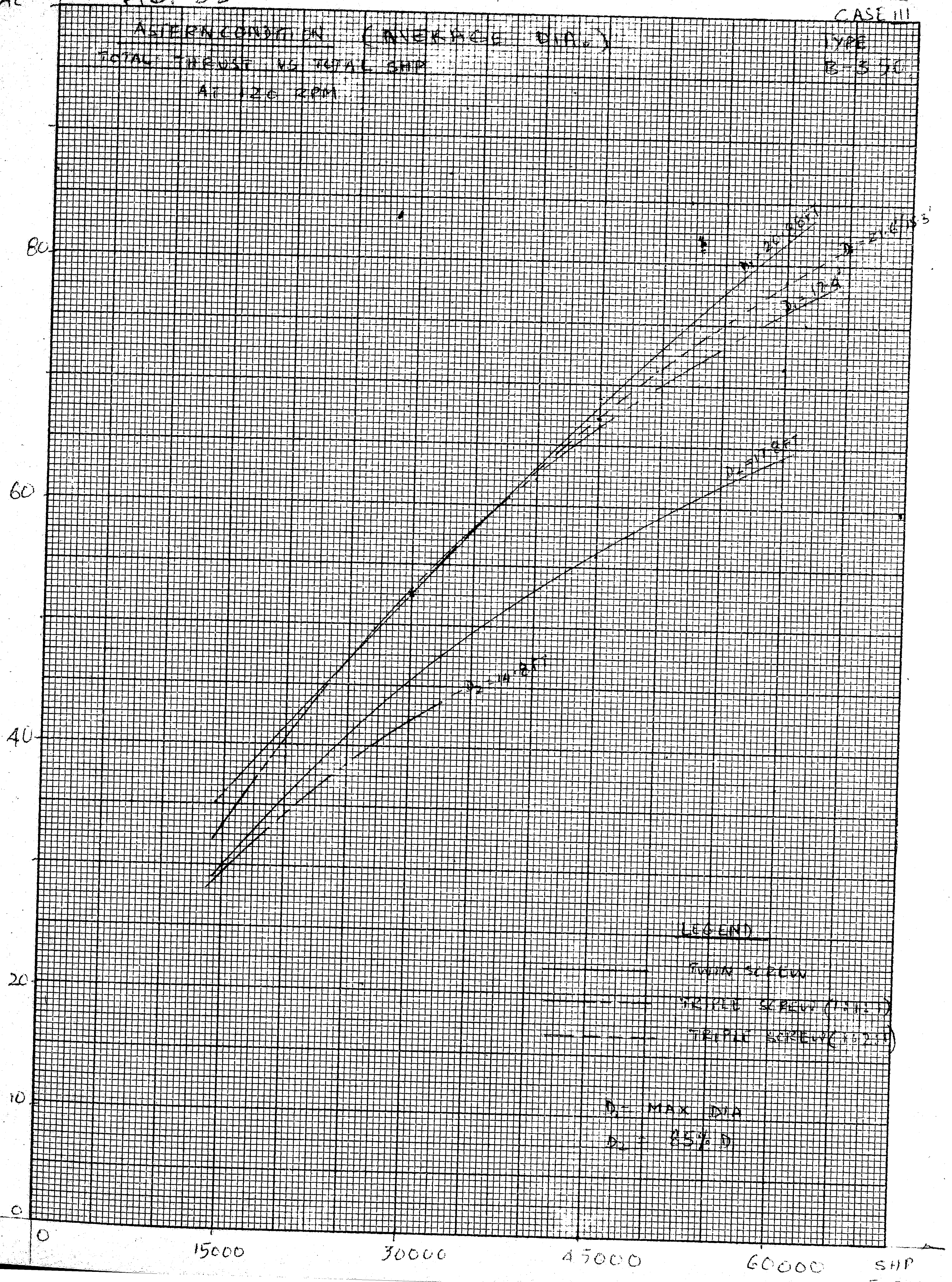
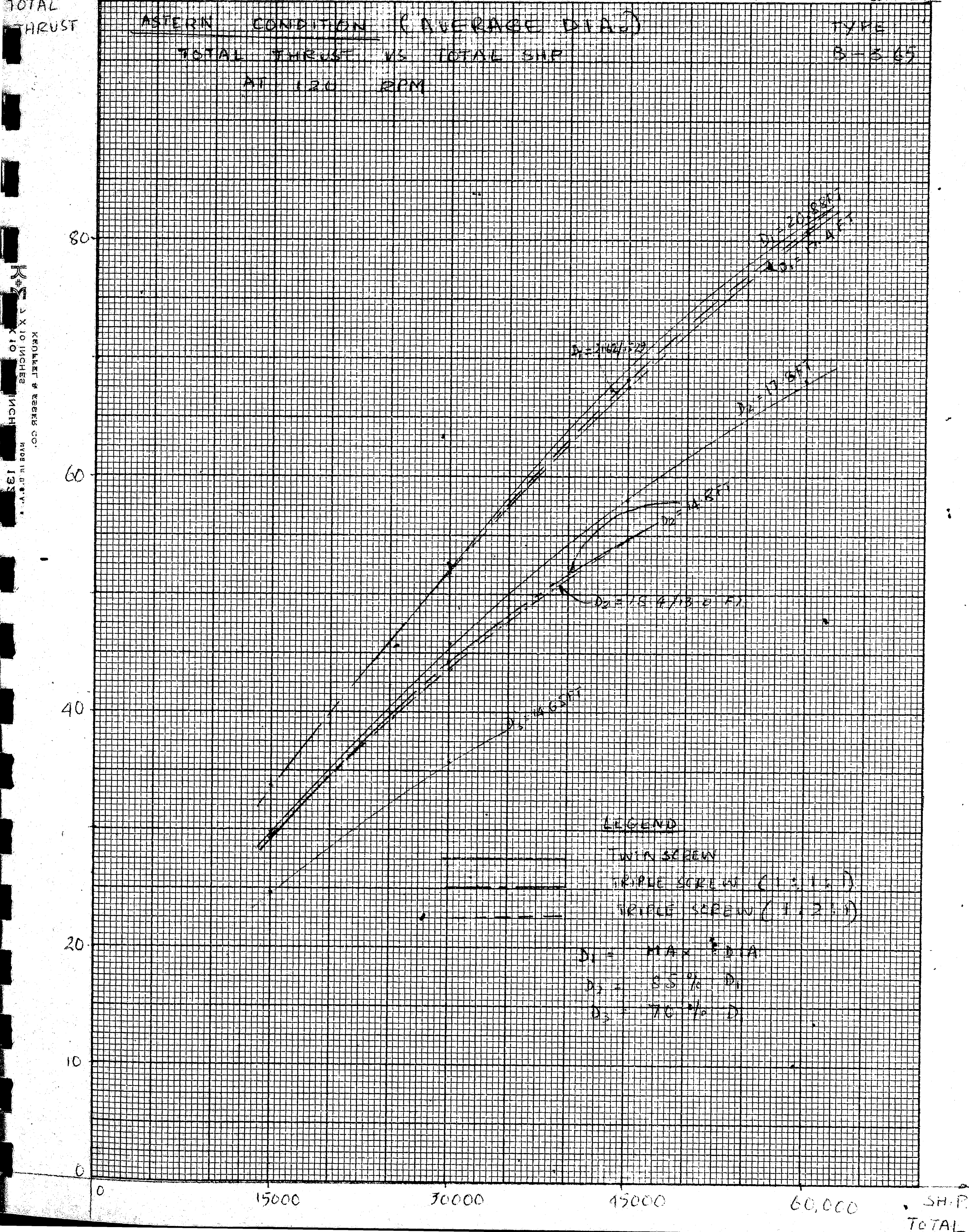
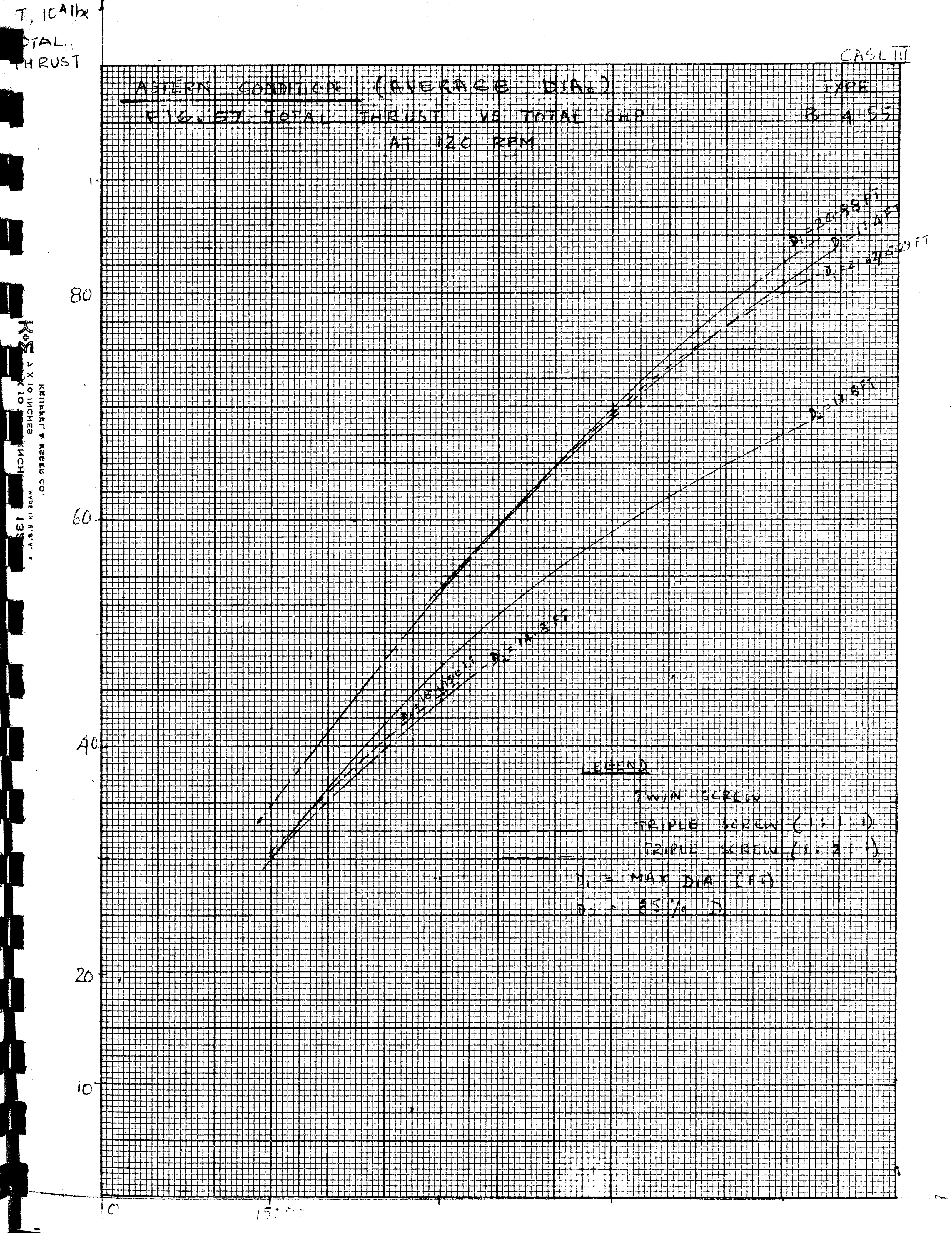
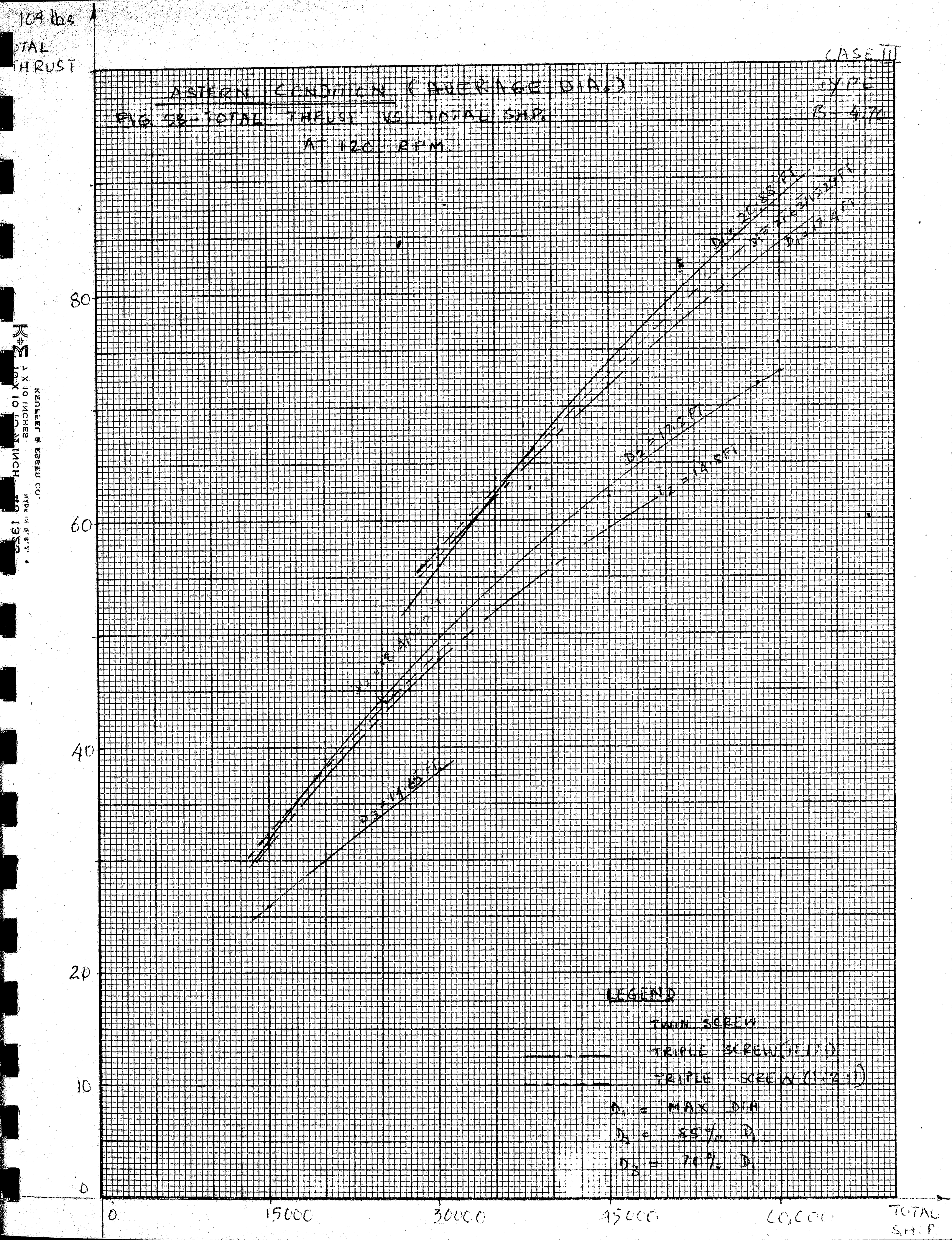
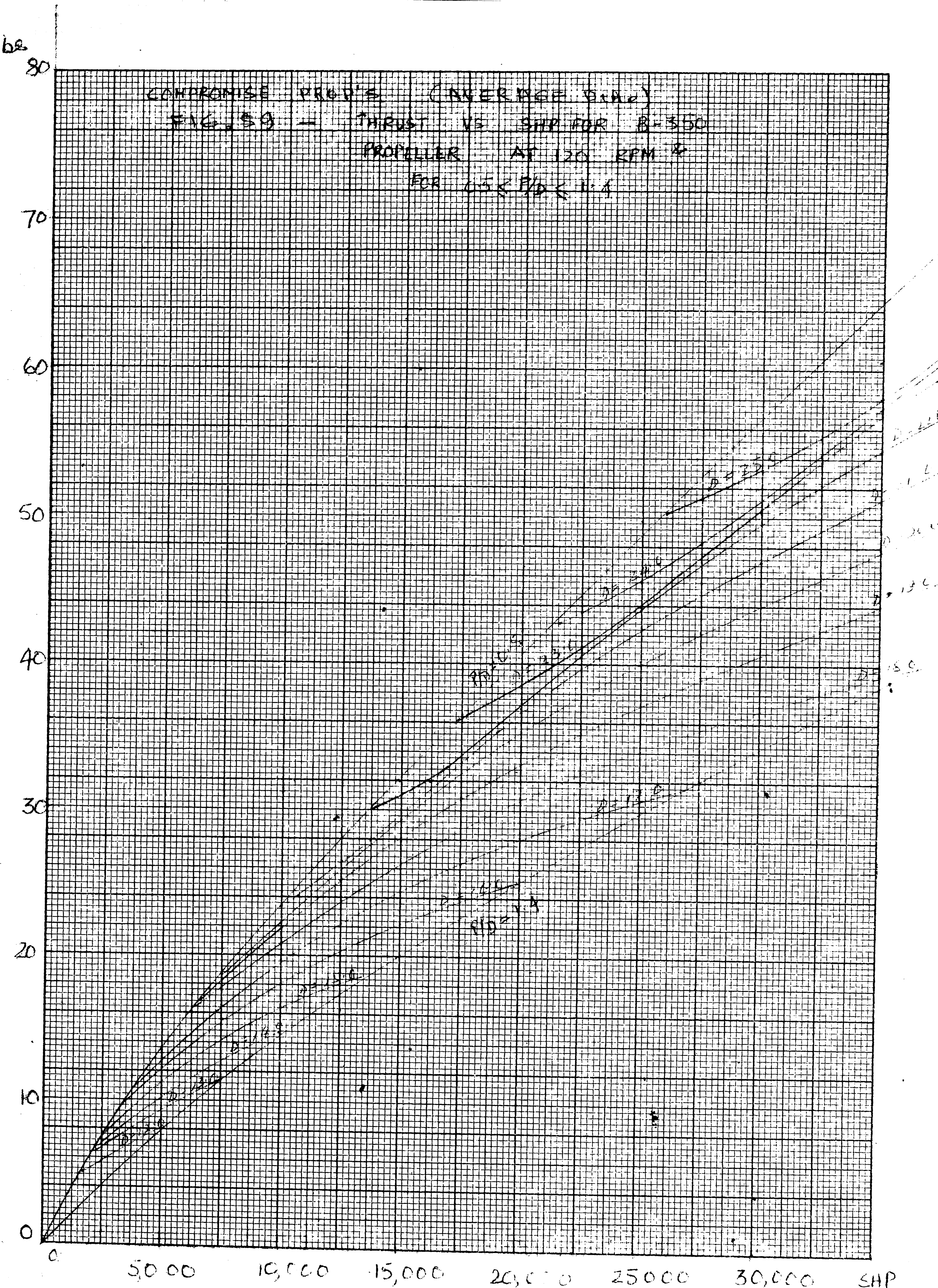

THRUST
TOTAL
ASTERN CONDITION (AVERAGE DIA.)
TOTAL THRUST VS TOTAL SHP
AT 120 RPM
CASE III
TYPE
B-3.50
80
60
40
20
10
0
0
15000
30000
45000
60000
SHP
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D₁ = MAX DIA
D₂ = 85% D

FIG. 56

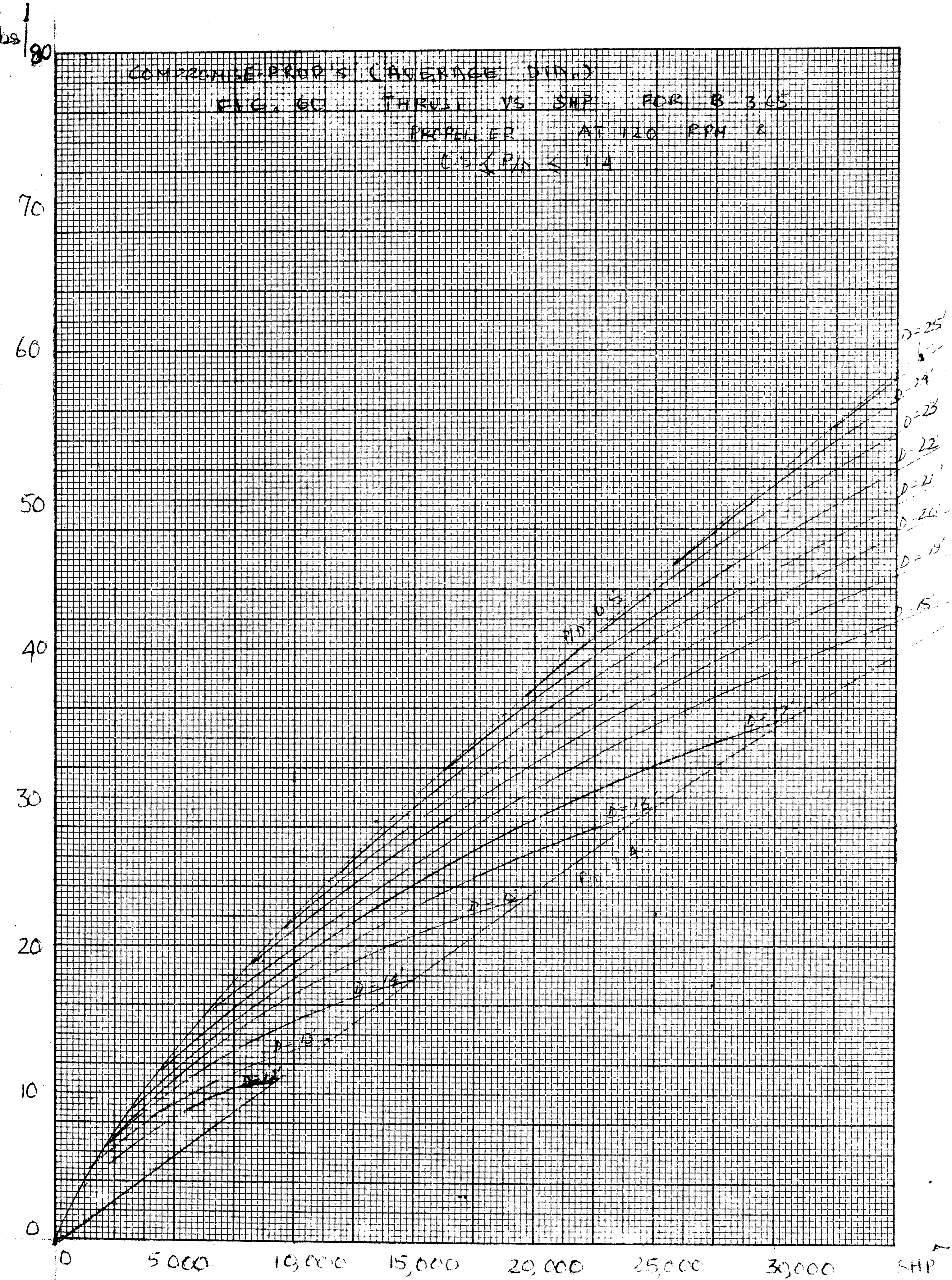

CASE III
TOTAL THRUST
ASTERN CONDITION (AVERAGE DIA.)
TOTAL THRUST VS TOTAL SHP
AT 120 RPM
TYPE
B-3.65
0
10
20
40
60
80
15000
30000
45000
60,000
SHP TOTAL
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D1 = MAX DIA
D2 = 85 % D1
D3 = 70 % D1
D2 = 15.4/13.8 FT
D2 = 17.8 FT
D2 = 14.8 FT
D3 = 14.65 FT
D1 = 20.8 FT

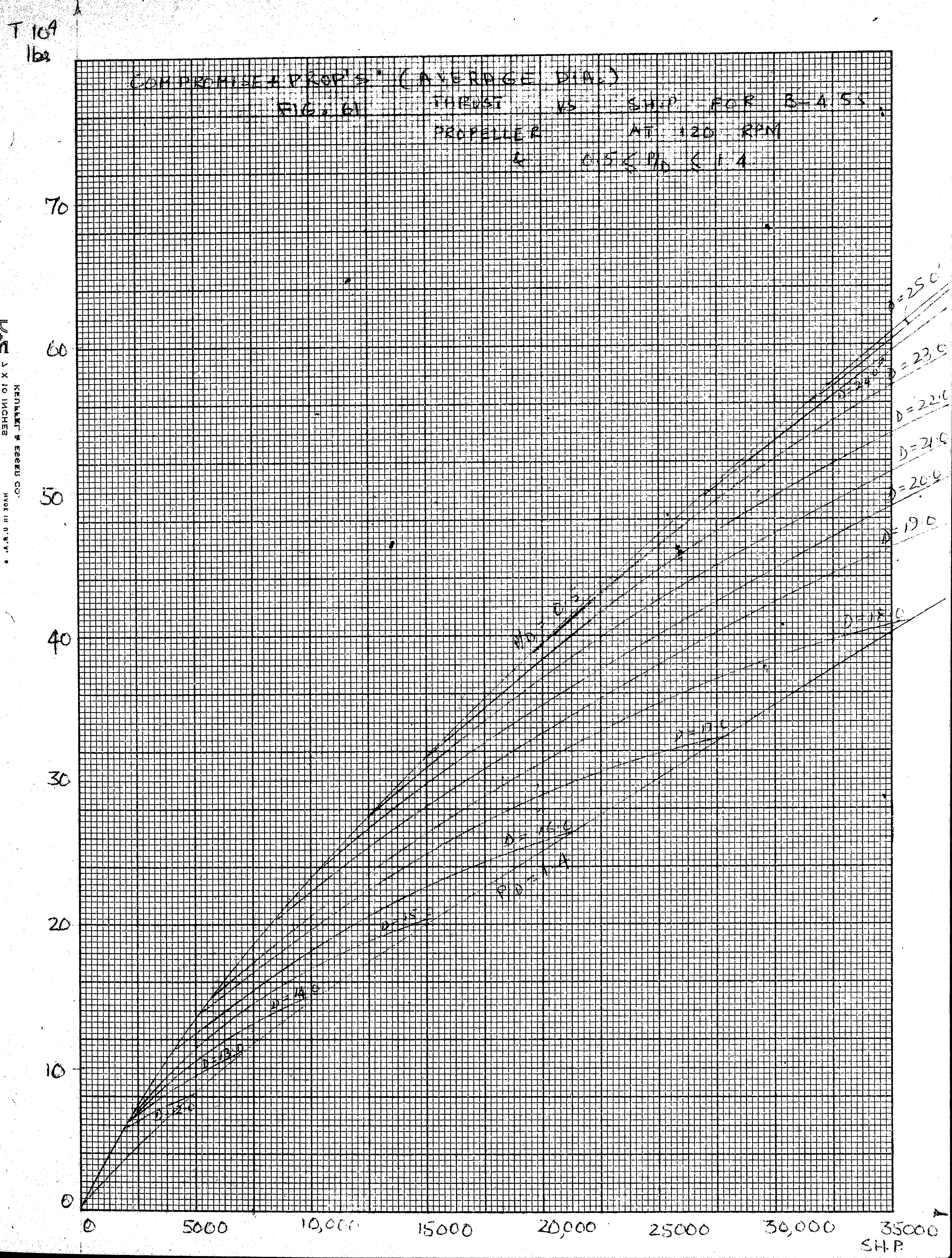

T, 10^4 lbs
TOTAL THRUST
CASE III
ASTERN CONDITION (AVERAGE DIA.)
FIG. 57 - TOTAL THRUST VS TOTAL SHP
AT 120 RPM
TYPE
B-4.55
80
60
40
20
10
0
15000
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D1 = MAX DIA (FT)
D2 = 85% D1


CASE III
TYPE
B- 4.70
ASTERN CONDITION (AVERAGE DIA.)
FIG 58 - TOTAL THRUST VS TOTAL SHP.
AT 120 RPM
10^4 lbs
TOTAL THRUST
80
60
40
20
10
0
0
15000
30000
45000
60,000
TOTAL S.H.P.
D1 = 20.88 FT
D1 = 17.4 FT
D2 = 17.8 FT
D2 = 14.8 FT
D3 = 14.65 FT
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D1 = MAX DIA
D2 = 85% D1
D3 = 70% D1

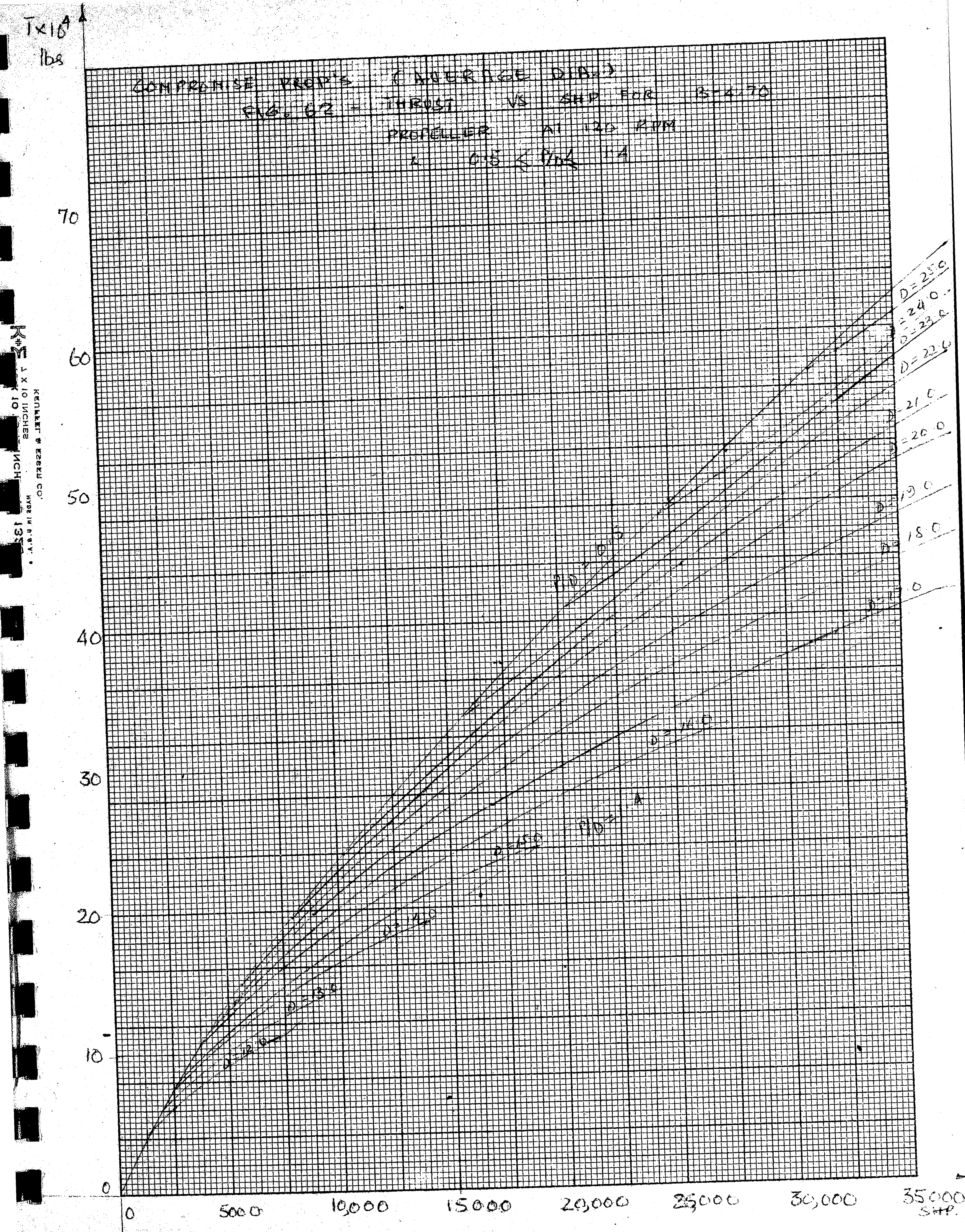


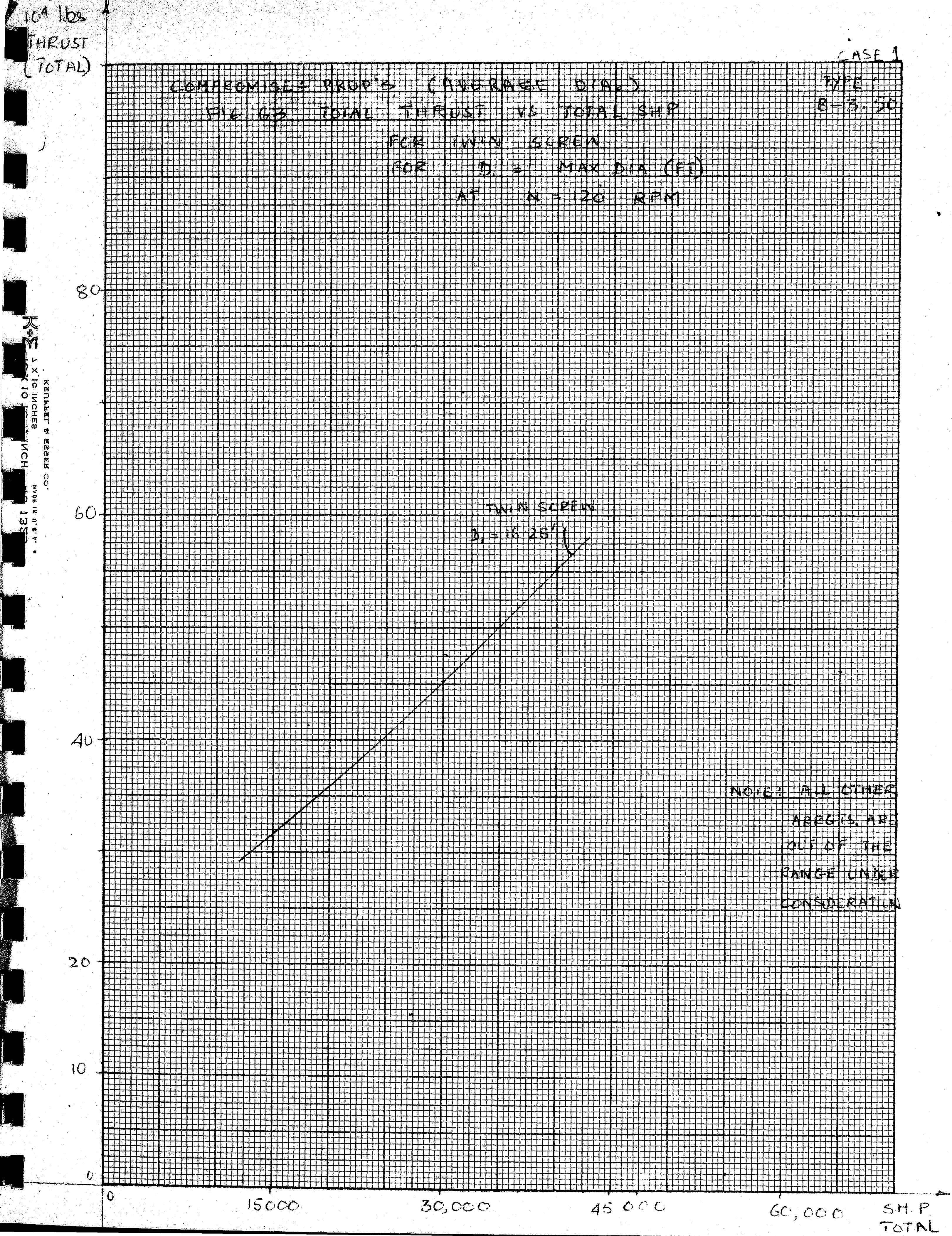
COMPROMISE PROP'S (AVERAGE D.A.)
FIG. 59 — THRUST VS SHP FOR B-3.50
PROPELLER AT 120 RPM &
FOR 0.5 ≤ P/D ≤ 1.4
T lbs
80
70
60
50
40
30
20
10
0
P/D = 0.5
P/D = 1.4
0
5000
10,000
15,000
20,000
25000
30,000
SHP


COMPROMISE PROP'S (AVERAGE DIA.)
FIG. 60 THRUST VS SHP FOR B-3.65
PROPELLER AT 120 RPM &
0.5 ≤ P/D ≤ 1.4
T 10^4 lbs
0
10
20
30
40
50
60
70
80
SHP
0
5000
10,000
15,000
20,000
25,000
30,000
D=25'
D=24'
D=23'
D=22'
D=21'
D=20'
D=19'
D=18'
D=17
D=16
D=15
D=14'
D=13
D=12'
P/D=0.5
P/D=1.4

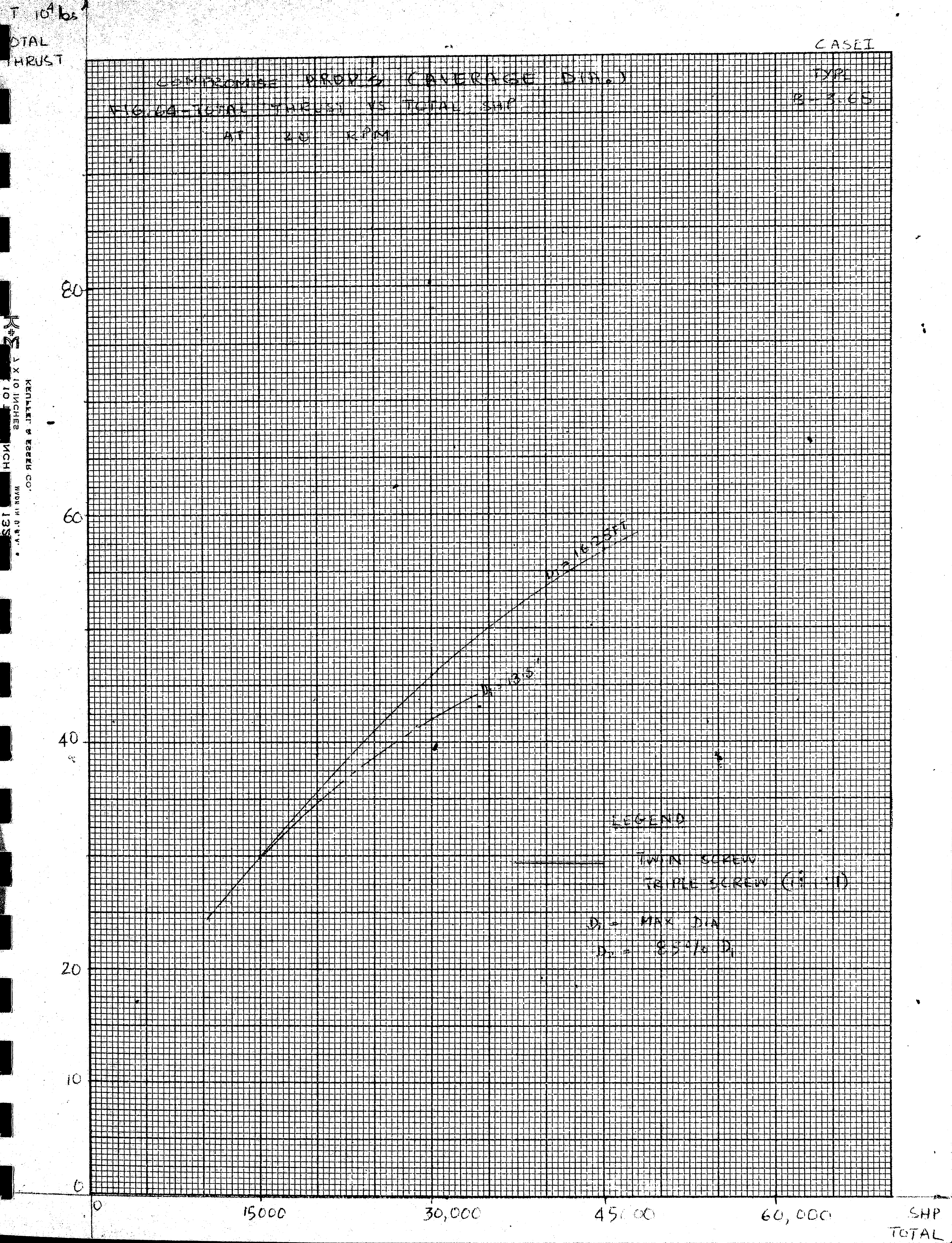


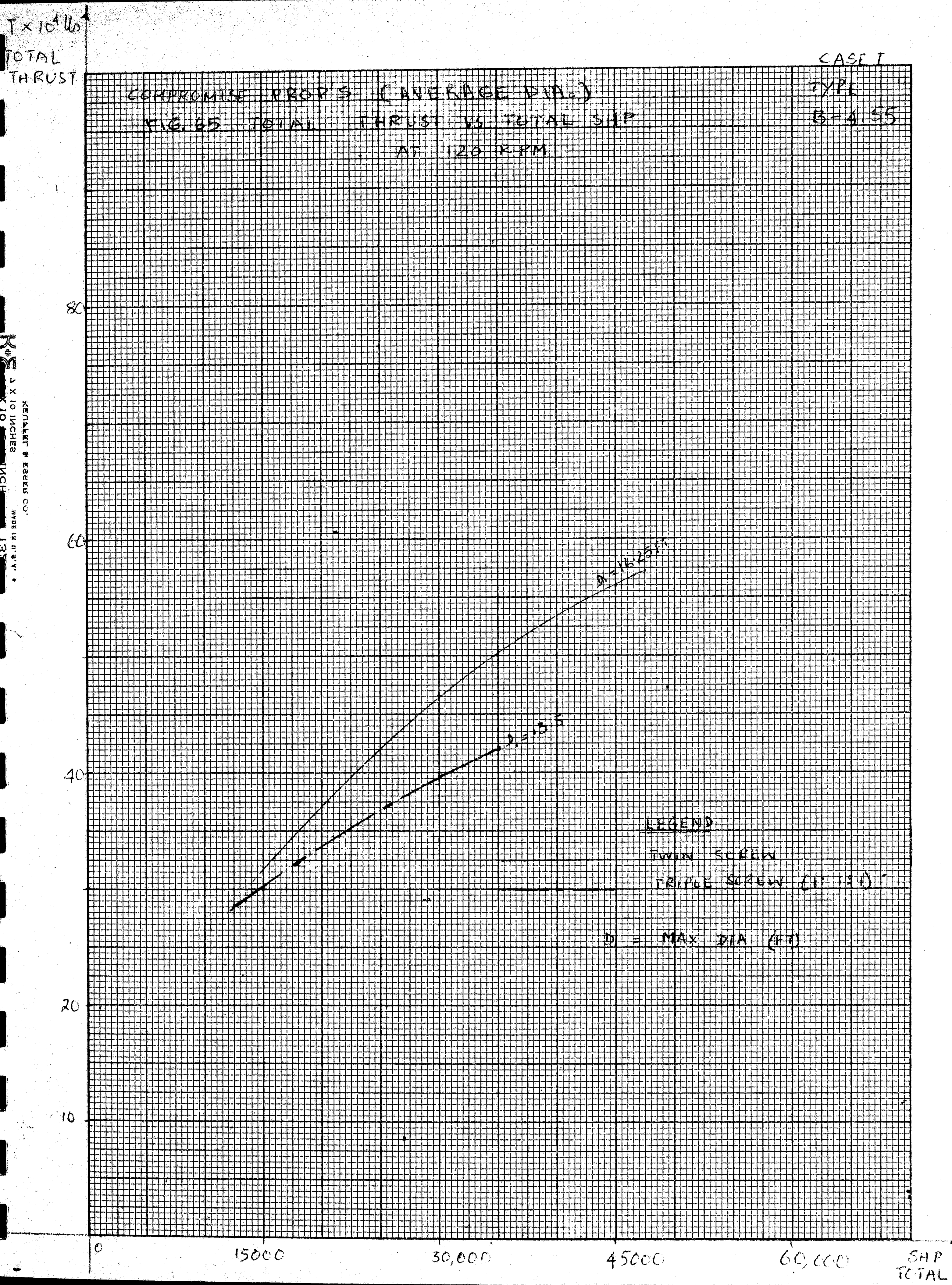
T 10^4 lbs
COMPROMISE PROP'S (AVERAGE DIA.)
FIG. 61
THRUST VS S.H.P FOR B-4.55
PROPELLER AT 120 RPM
& 0.5 ≤ P/D ≤ 1.4
0
10
20
30
40
50
60
70
0
5000
10,000
15000
20,000
25000
30,000
35000
S.H.P.
D = 25.0'
D = 24.0
D = 23.0
D = 22.0
D = 21.0
D = 20.0
D = 19.0
D = 18.0
D = 17.0
D = 16.0
D = 15
D = 14.0
D = 13.0
D = 12.0
P/D = 0.5
P/D = 1.4


COMPROMISE PROP'S (AVERAGE DIA.)
FIG. 62 - THRUST VS SHP FOR B-4.70
PROPELLER AT 120 RPM
& 0.5 < P/D < 1.4
T×10⁴ lbs
70
60
50
40
30
20
10
0
0
5000
10,000
15000
20,000
25000
30,000
35000
SHP
D = 25.0
D = 24.0
D = 23.0
D = 22.0
D = 21.0
D = 20.0
D = 19.0
D = 18.0
D = 17.0
D = 16.0
D = 15.0
D = 14.0
D = 13.0
D = 12.0
P/D = 0.5
P/D = 1.4

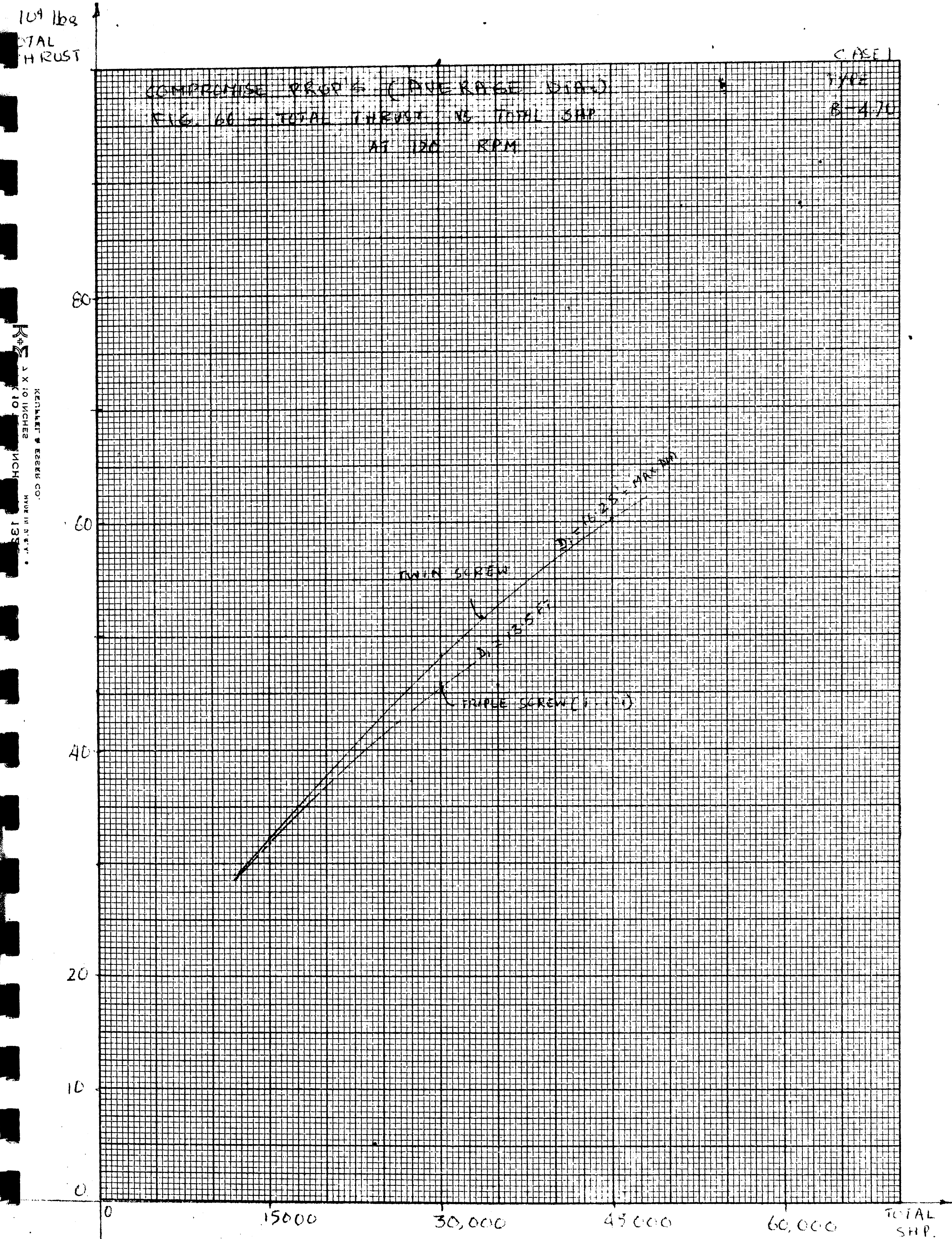


CASE 1
TYPE:
B-3.50
COMPROMISE PROP'S (AVERAGE DIA.)
FIG 63 TOTAL THRUST VS TOTAL SHP
FOR TWIN SCREW
FOR D = MAX DIA (FT)
AT N = 120 RPM
10⁴ lbs THRUST (TOTAL)
80
60
40
20
10
0
TWIN SCREW
D = 16.25'
NOTE: ALL OTHER
ARRGTS. ARE
OUT OF THE
RANGE UNDER
CONSIDERATION
0
15000
30,000
45,000
60,000
SH.P. TOTAL


CASE I
COMPROMISE PROP'S (AVERAGE DIA.)
TYPE
B-3.65
FIG. 64 - TOTAL THRUST VS TOTAL SHP
AT RPM
T 10^4 lbs
TOTAL
THRUST
80
60
40
20
10
0
0
15000
30,000
45,000
60,000
SHP
TOTAL
D = 16.25 FT
D = 13.5'
LEGEND
TWIN SCREW
TRIPLE SCREW
D_1 = MAX DIA
D_2 = 85% D_1



T × 10⁴ lb
TOTAL THRUST
CASE I
TYPE B-4.55
COMPROMISE PROP'S (AVERAGE DIA.)
FIG. 65 TOTAL THRUST VS TOTAL SHP
AT 120 RPM
D = 16.25 FT
D = 13.5
LEGEND
TWIN SCREW
TRIPLE SCREW
D = MAX DIA (FT)
80
60
40
20
10
0
15000
30,000
45000
60,000
SHP TOTAL



10⁴ lbs
TOTAL THRUST
CASE I
TYPE
B-4.70
COMPROMISE PROP'S (AVERAGE DIA.)
FIG. 60 – TOTAL THRUST VS TOTAL SHP
AT 120 RPM
80
60
40
20
10
0
TWIN SCREW
D = 16.25' = MAX DIA
D = 13.5 FT
TRIPLE SCREW (1 - 1 - 1)
0
15000
30,000
45000
60,000
TOTAL SHP.

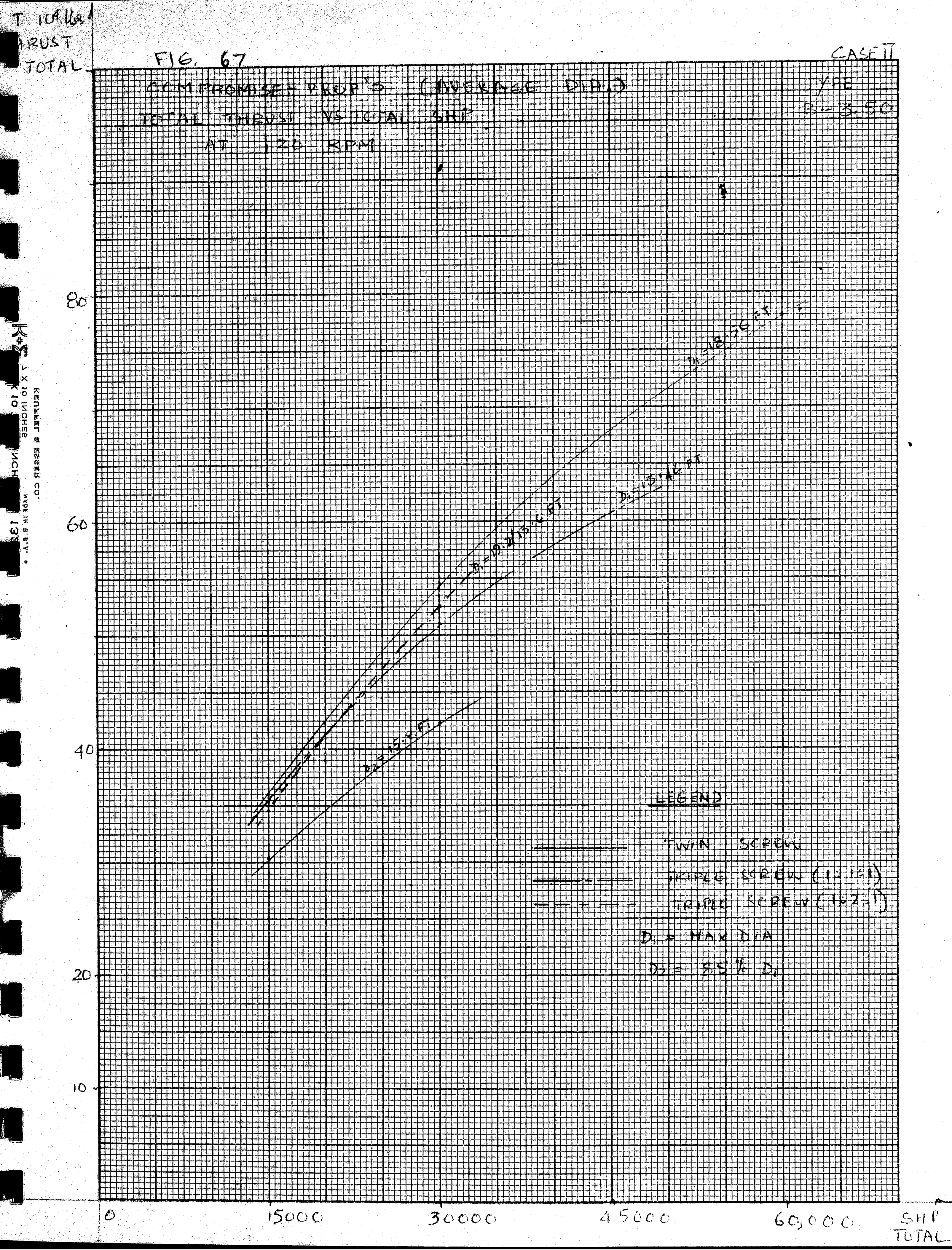


FIG. 67
COMPROMISE PROP'S (AVERAGE DIA)
TOTAL THRUST VS TOTAL SHP
AT 120 RPM
CASE II
TYPE
R = 3.50
T 10^4 lbs
THRUST TOTAL
80
60
40
20
10
0
15000
30000
45000
60,000
SHP TOTAL
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D_1 = MAX DIA
D_2 = 85% D_1

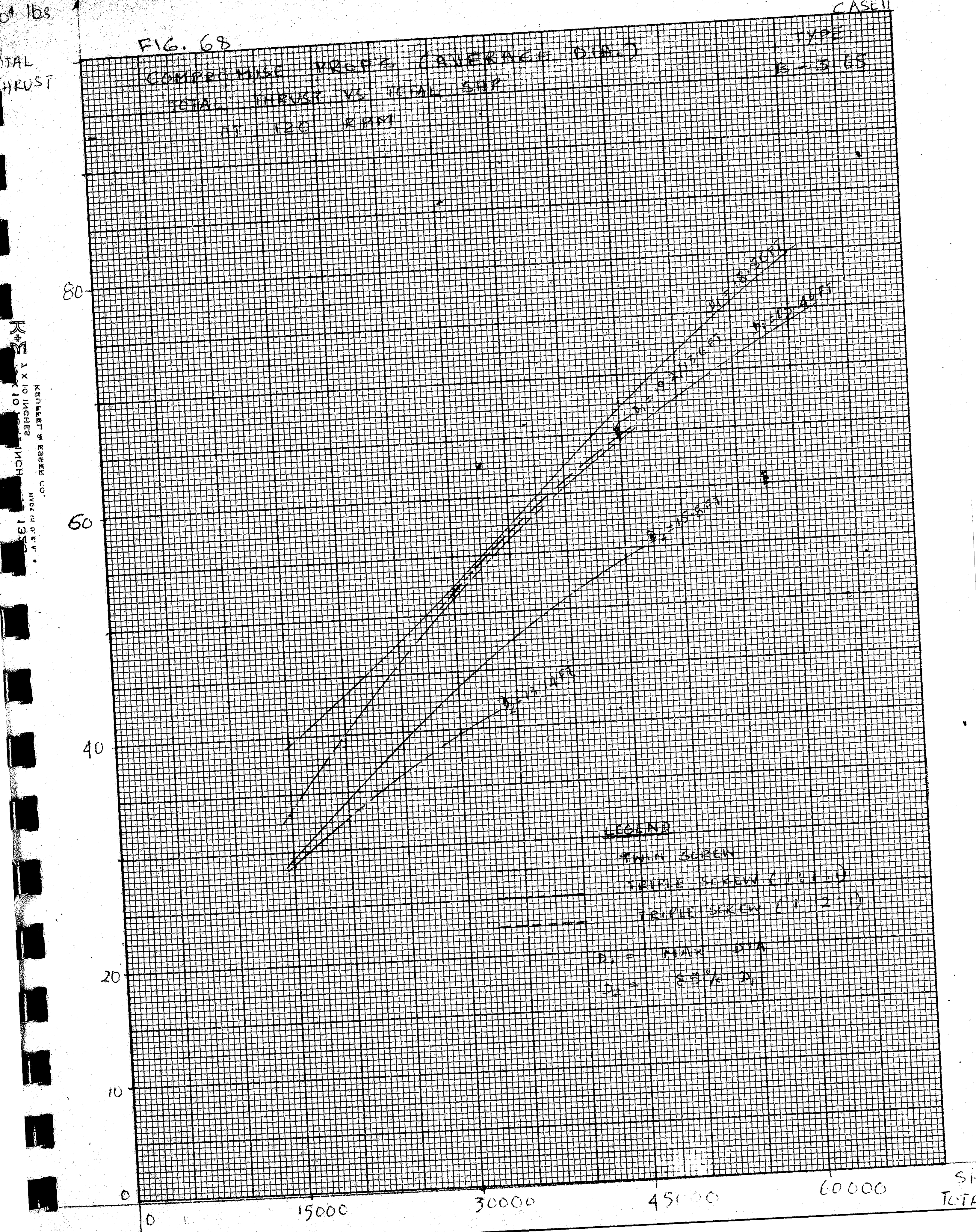
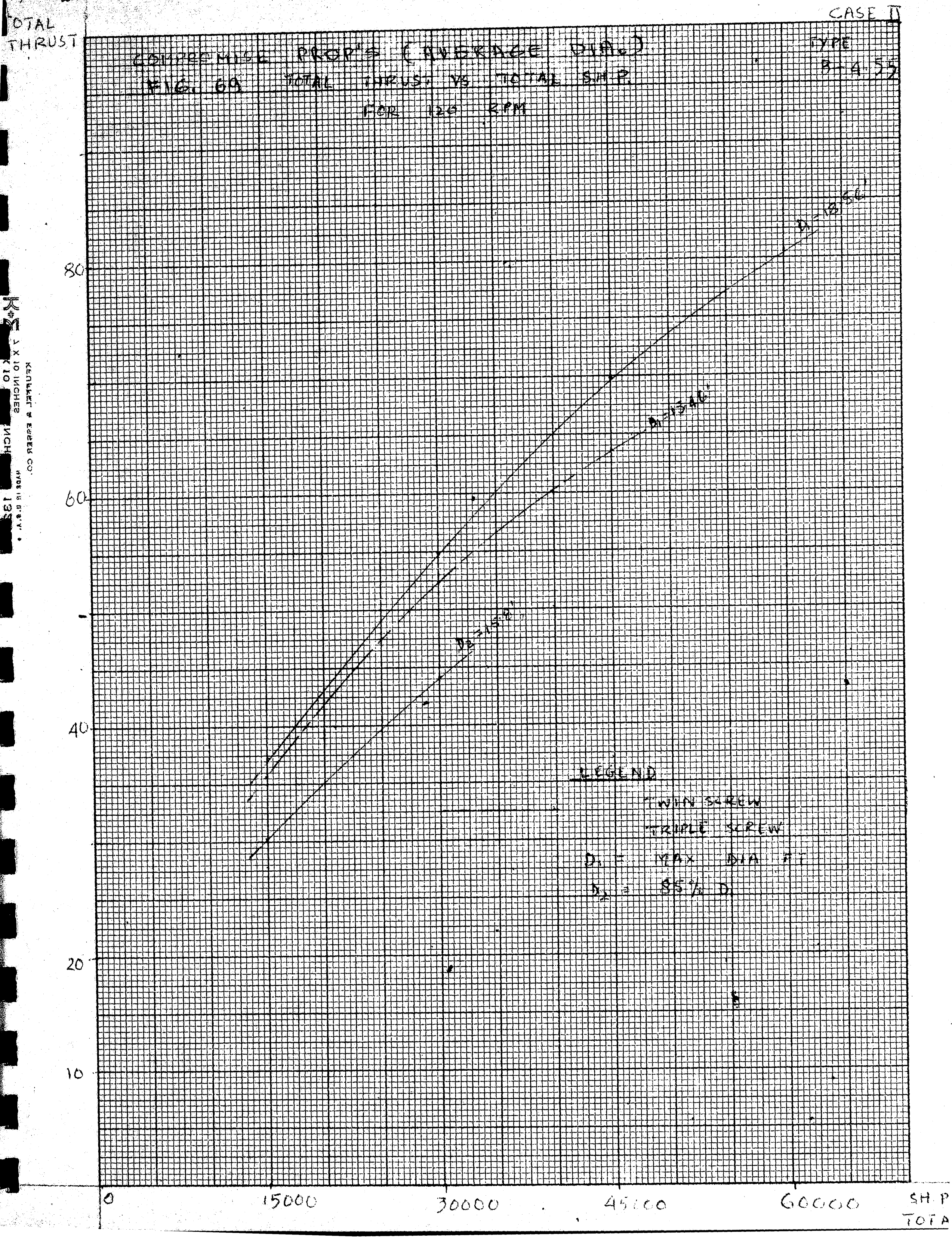
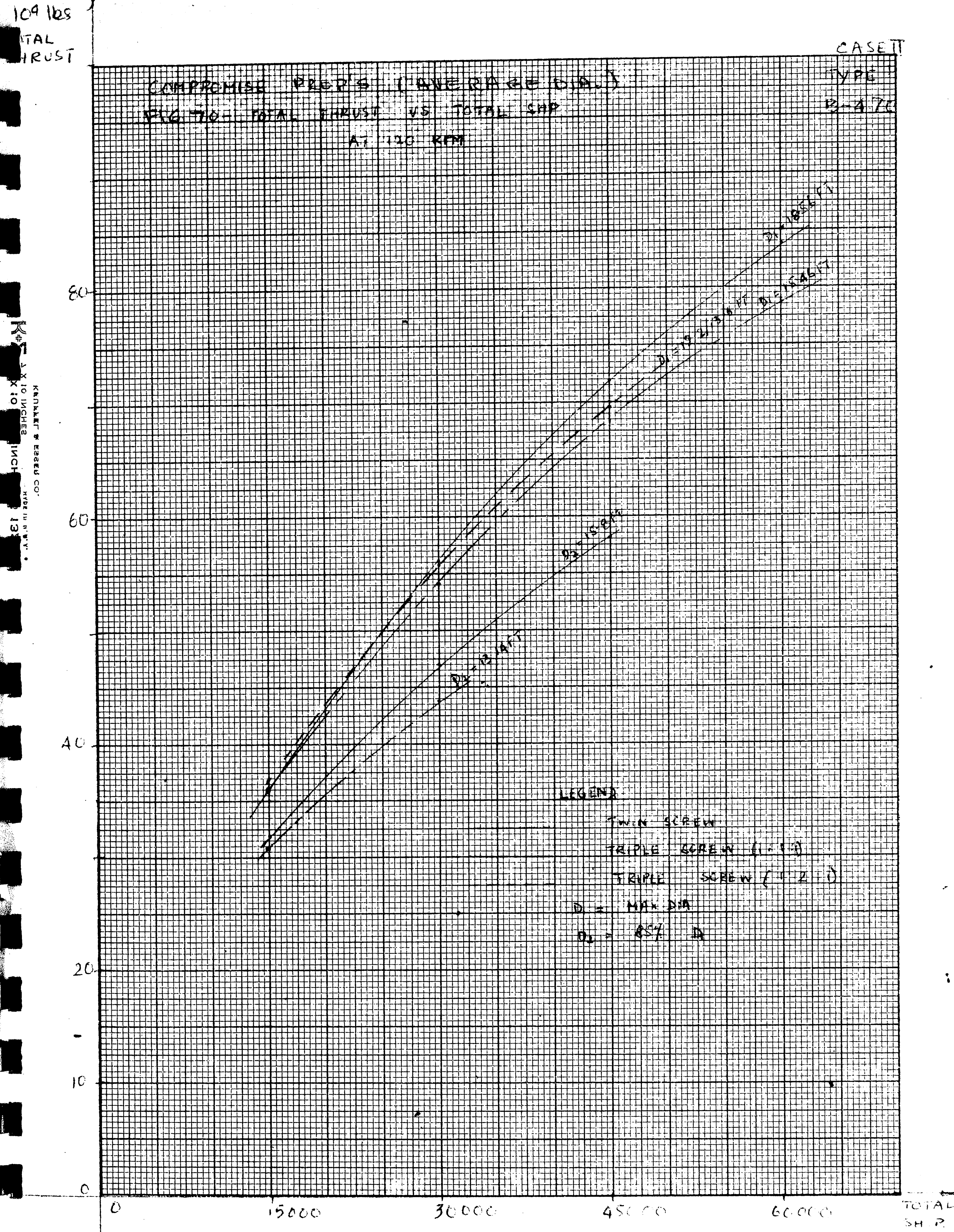


FIG. 68
COMPROMISE PROPS (AVERAGE DIA.)
TOTAL THRUST VS TOTAL SHP
AT 120 RPM
CASE II
TYPE
S - 5 65
10^4 lbs
TOTAL THRUST
0
10
20
40
60
80
0
15000
30000
45000
60000
SHP TOTAL
D1 = 18.30 FT
D1 = 17.45 FT
D2 = 15.3 FT
D2 = 15.8 FT
D2 = 13.4 FT
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D1 = MAX DIA
D2 = 85% D1


CASE II
TYPE
B-4.55
COMPROMISE PROP'S (AVERAGE DIA.)
FIG. 69 TOTAL THRUST VS TOTAL SH.P.
FOR 120 RPM
T, 10⁴ lbs
TOTAL THRUST
80
60
40
20
10
0
15000
30000
45000
60000
SH.P TOTA
D_1=18.56'
D_1=13.46'
D_2=15.8'
LEGEND
TWIN SCREW
TRIPLE SCREW
D_1 = MAX DIA FT
D_2 = 85% D_1


CASE II
COMPROMISE PROP'S (AVERAGE DIA.)
FIG. 70 - TOTAL THRUST VS TOTAL SHP
AT 120 RPM
TOTAL THRUST
80
60
40
20
10
0
0
15000
30000
45000
60000
TOTAL SHP
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1)
TRIPLE SCREW (1:2)
D1 = MAX DIA

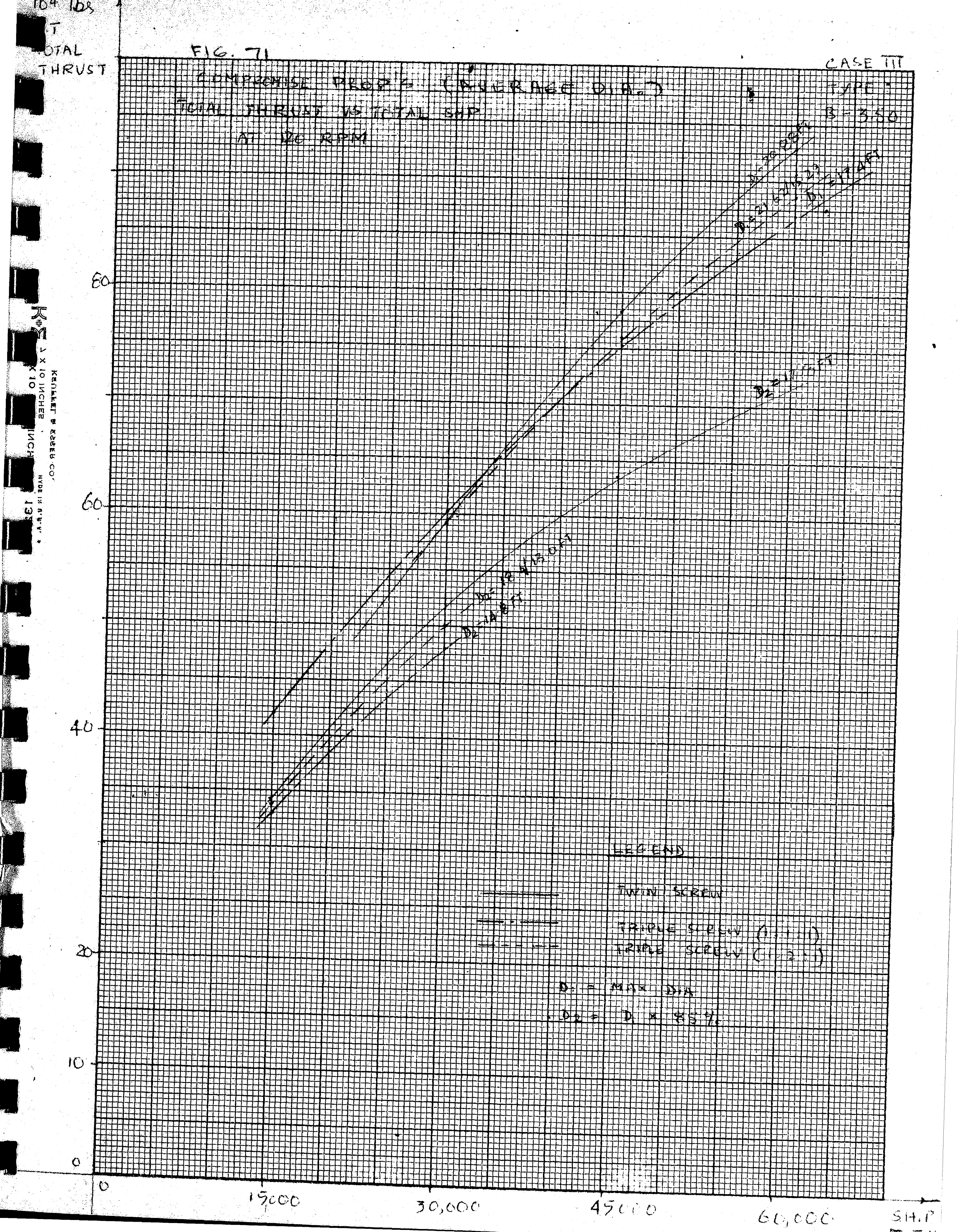
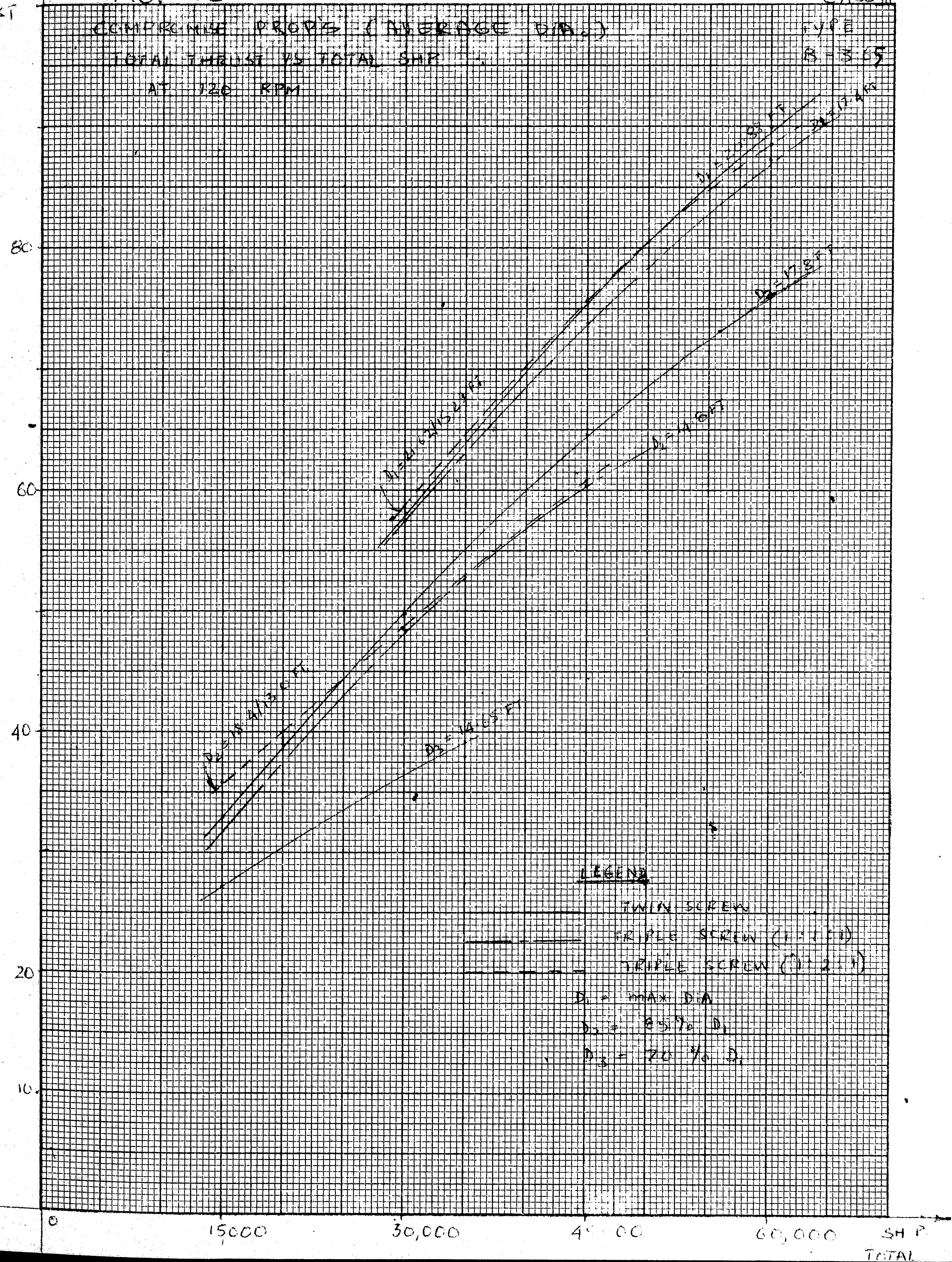
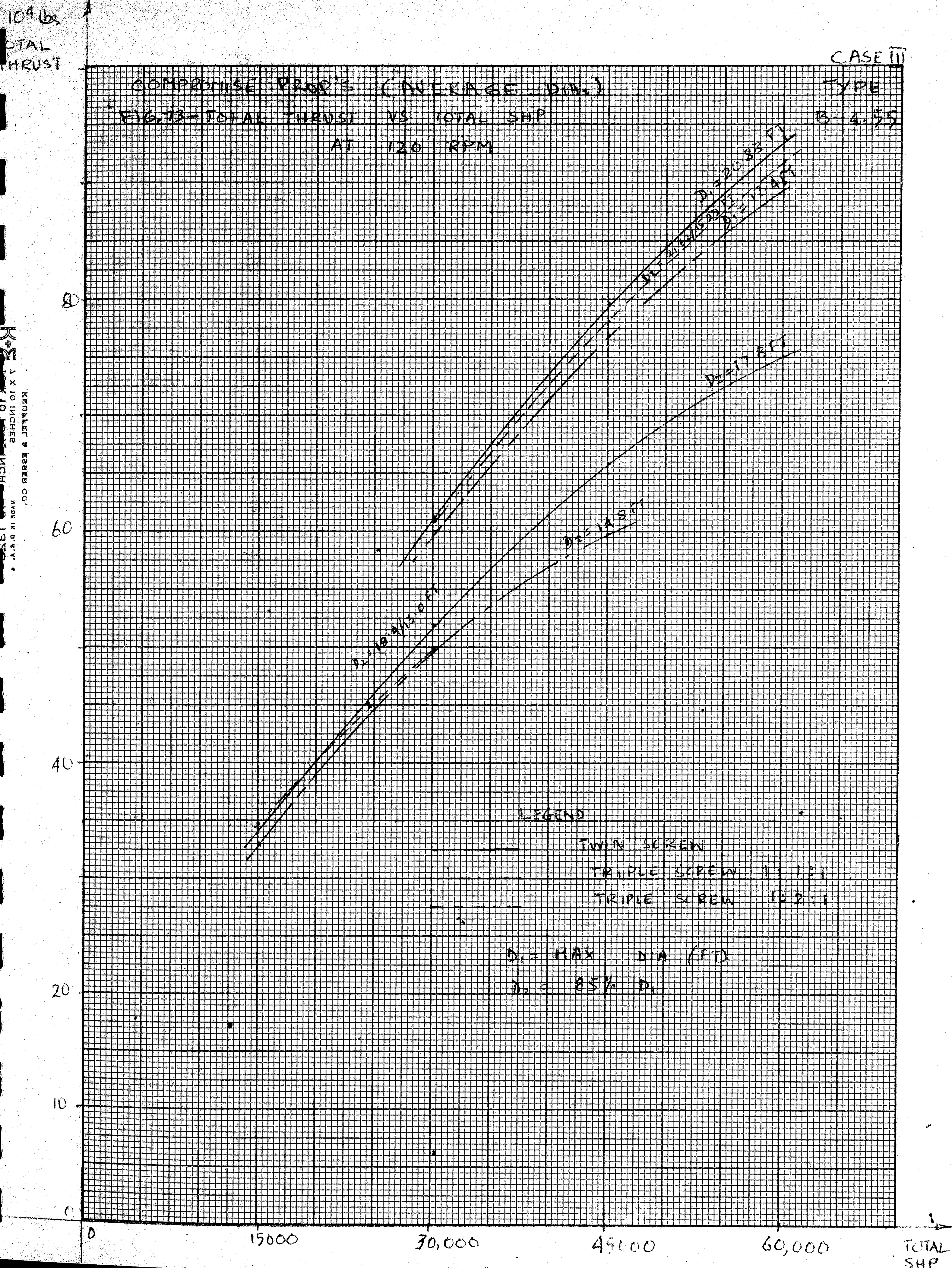


FIG. 71
COMPROMISE PROP. (AVERAGE DIA.)
TOTAL THRUST VS TOTAL SHP
AT 120 RPM
CASE III
TYPE:
B-3.50
10⁴ lbs
TOTAL THRUST
0
10
20
40
60
80
0
15,000
30,000
45,000
60,000
S.H.P.
D₁ = 20.88 FT
D₂ = 21.6
D₁ = 17.4 FT
D₂ = 17.6 FT
D₂ = 12.4 / 15.0 FT
D₂ = 14.8 FT
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D₁ = MAX DIA
D₂ = D₁ × 85%
KEUFFEL & ESSER CO.
MADE IN U.S.A.

T 10^4 lbs
TAL
THRUST

FIG. 72





10^4 lbs
TOTAL THRUST
CASE III
COMPROMISE PROP'S (AVERAGE DIA.)
FIG. 73 - TOTAL THRUST VS TOTAL SHP
AT 120 RPM
TYPE
B-4.55
D2 = 17.8 FT
D2 = 14.8 FT
LEGEND
TWIN SCREW
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:2:1
D1 = MAX DIA (FT)
D2 = 85% D1
0
10
20
40
60
80
15000
30,000
45000
60,000
TOTAL SHP

FIG 74

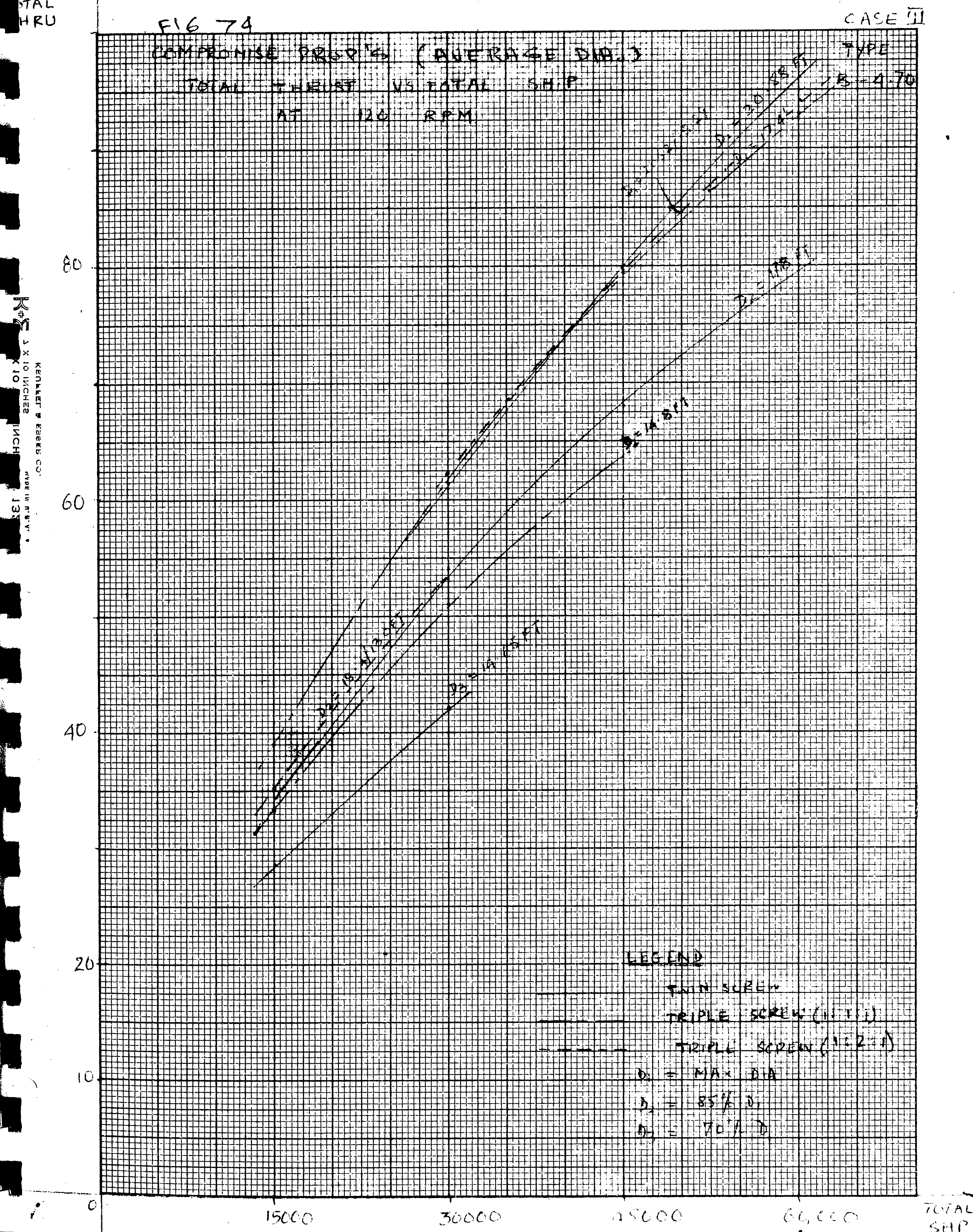
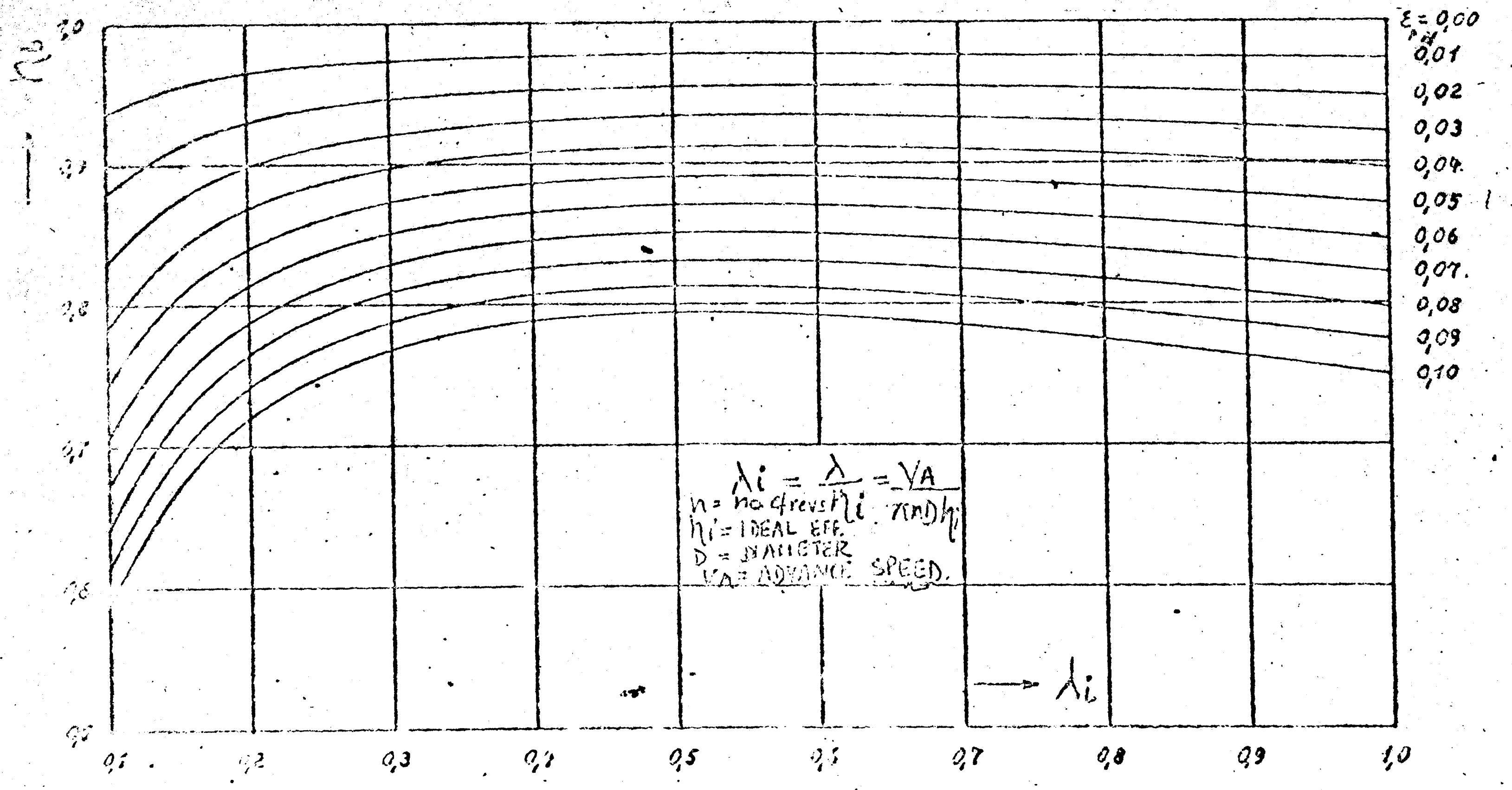

CASE II
COMPROMISE PROP'S (AVERAGE DIA.)
TOTAL THRUST VS TOTAL SHP
AT 126 RPM
TYPE
B-4.70
10^4 lbs
TOTAL THRU
80
60
40
20
10
0
15000
30000
45000
60,000
TOTAL SHP
LEGEND
TWIN SCREW
TRIPLE SCREW (1:1:1)
TRIPLE SCREW (1:2:1)
D1 = MAX DIA
D2 = 85% D1
D3 = 70% D1

FIG. 75: BLADE EFFICIENCY η_B OF PROPELLER AS A FUNCTION OF MEAN DRAG-LIFT RATIO AND INDUCED ADVANCE NUMBER λ_i

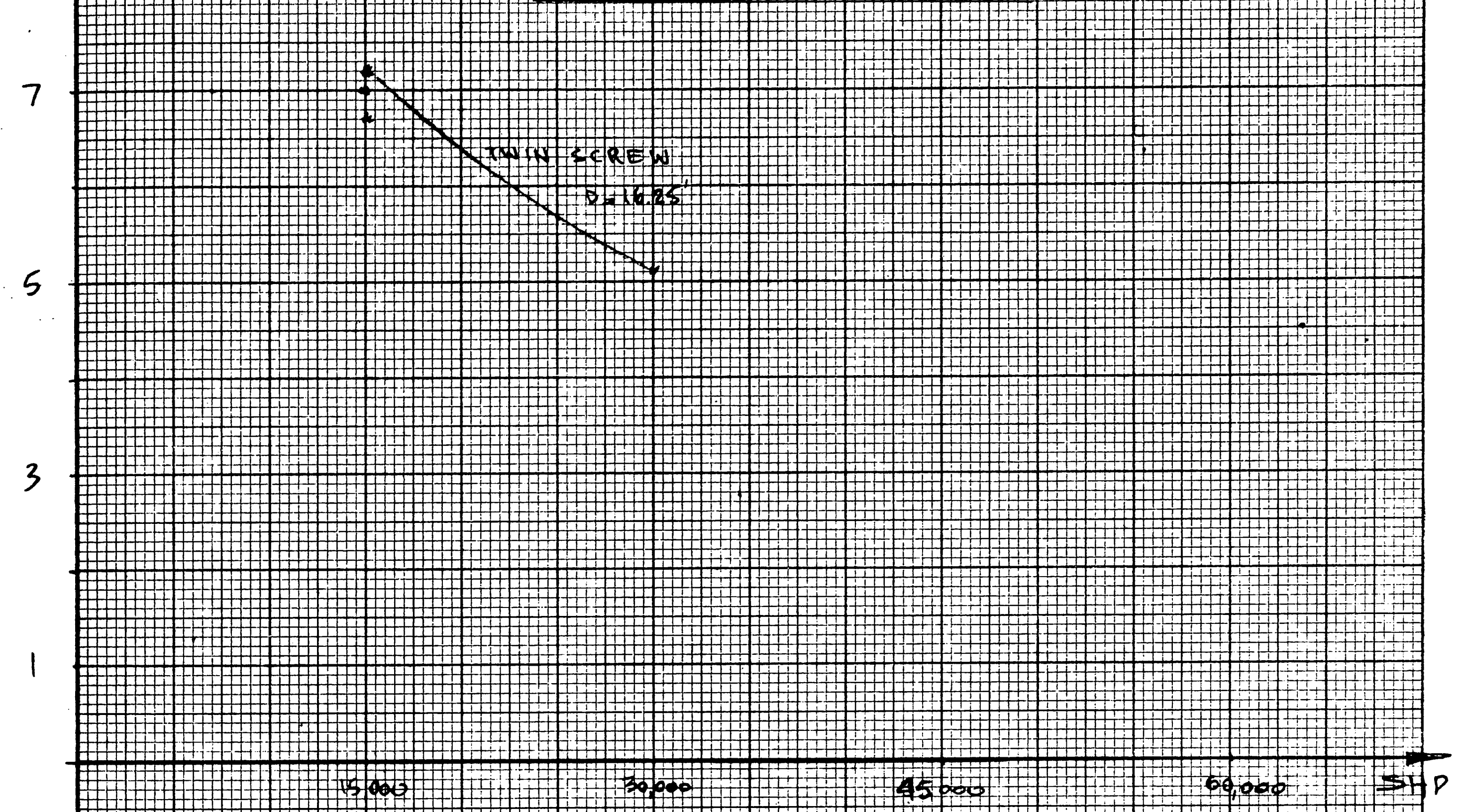


WHERE: $\varepsilon_{PM} = \frac{D}{L}$ (AVERAGE VALUE IN RADIAL DIRECTION)

THIS DIAGRAM WAS [illegible] FROM A CHART OF THE [illegible] [illegible]CAL [illegible] OF BERLIN

FIG. 76 PROPULSIVE EFFICIENCY AT 1 KNOT (AVERAGE DIA.)

CASE I, FOR B-3.50



CASE I, B-3.65

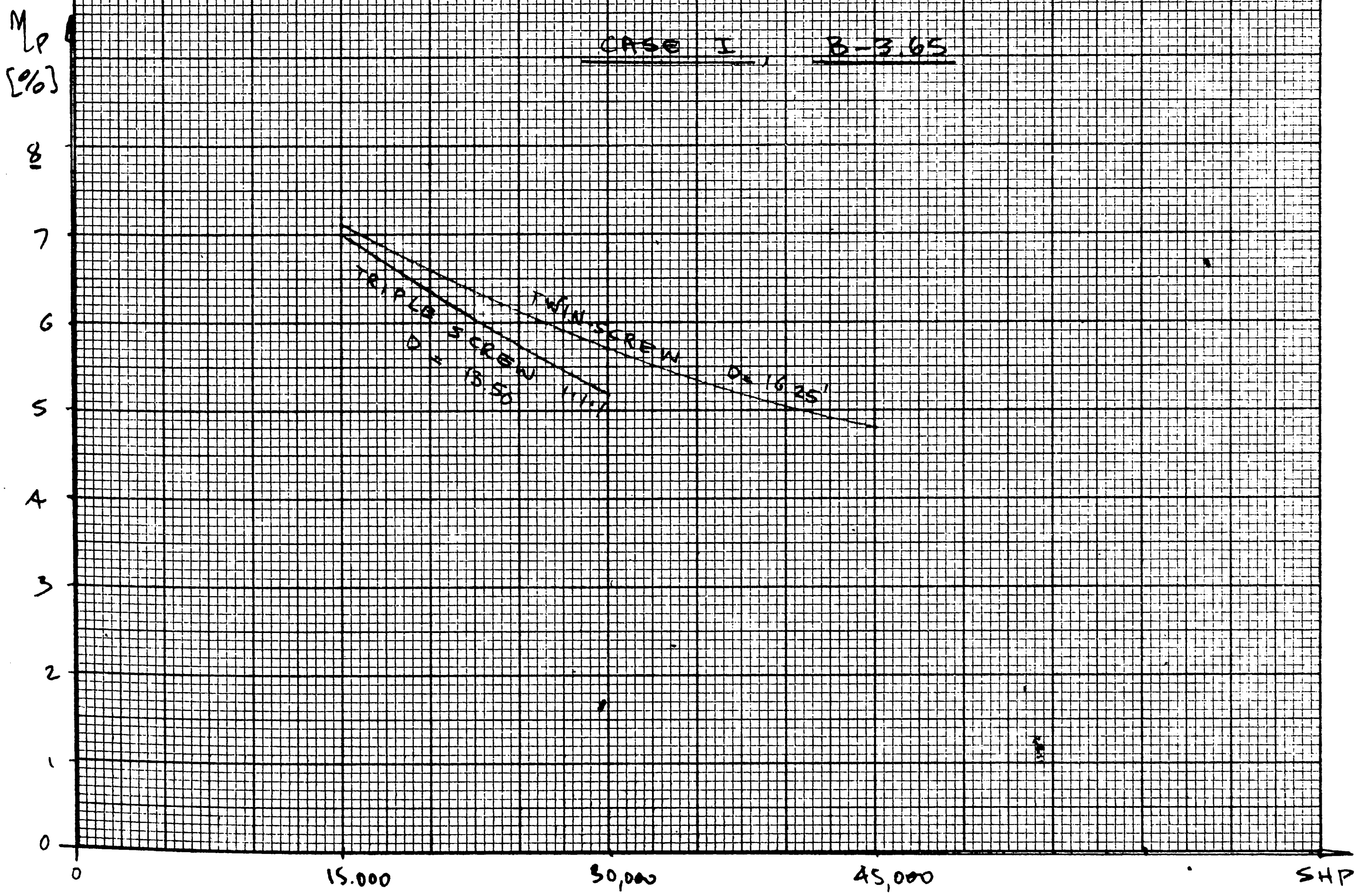
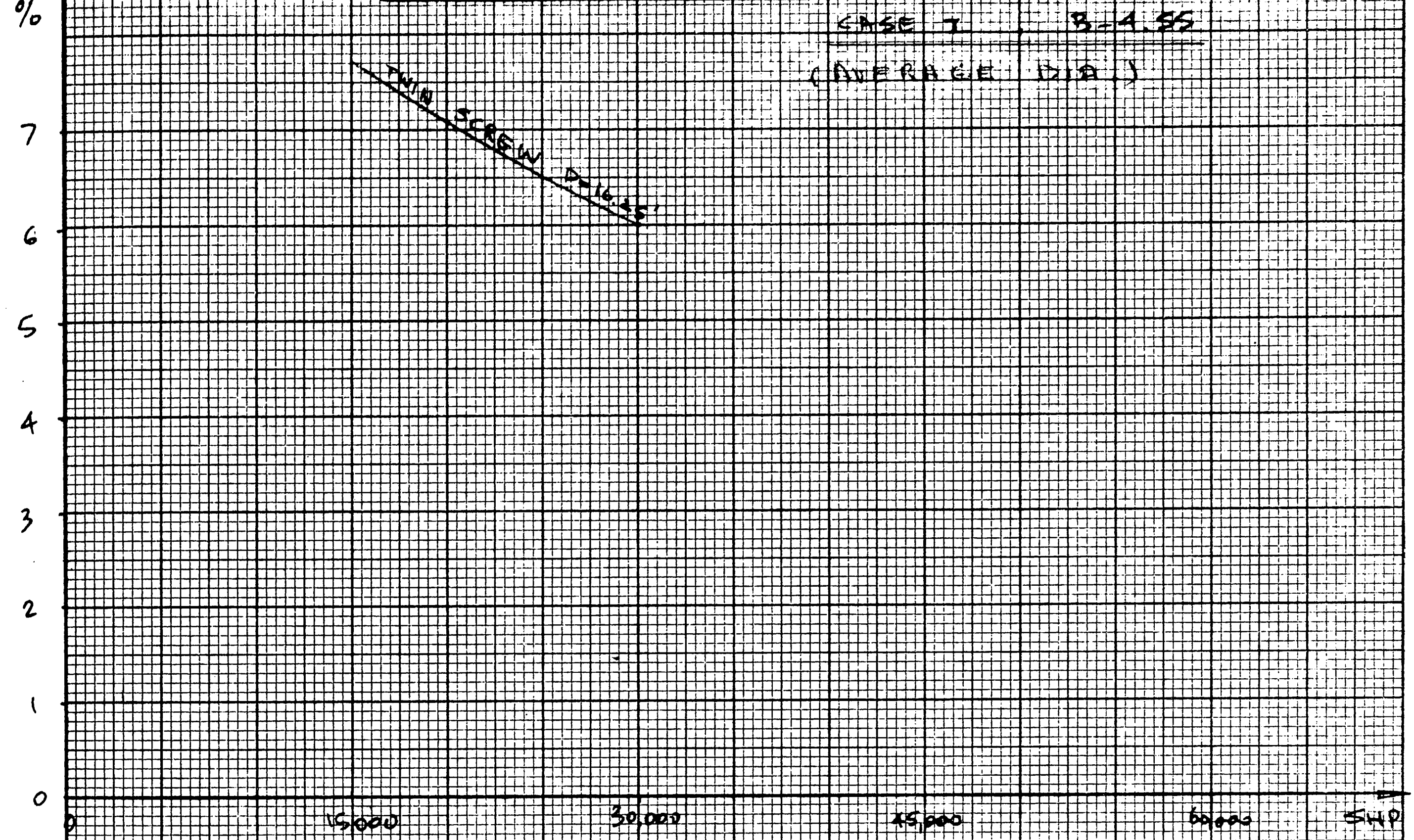
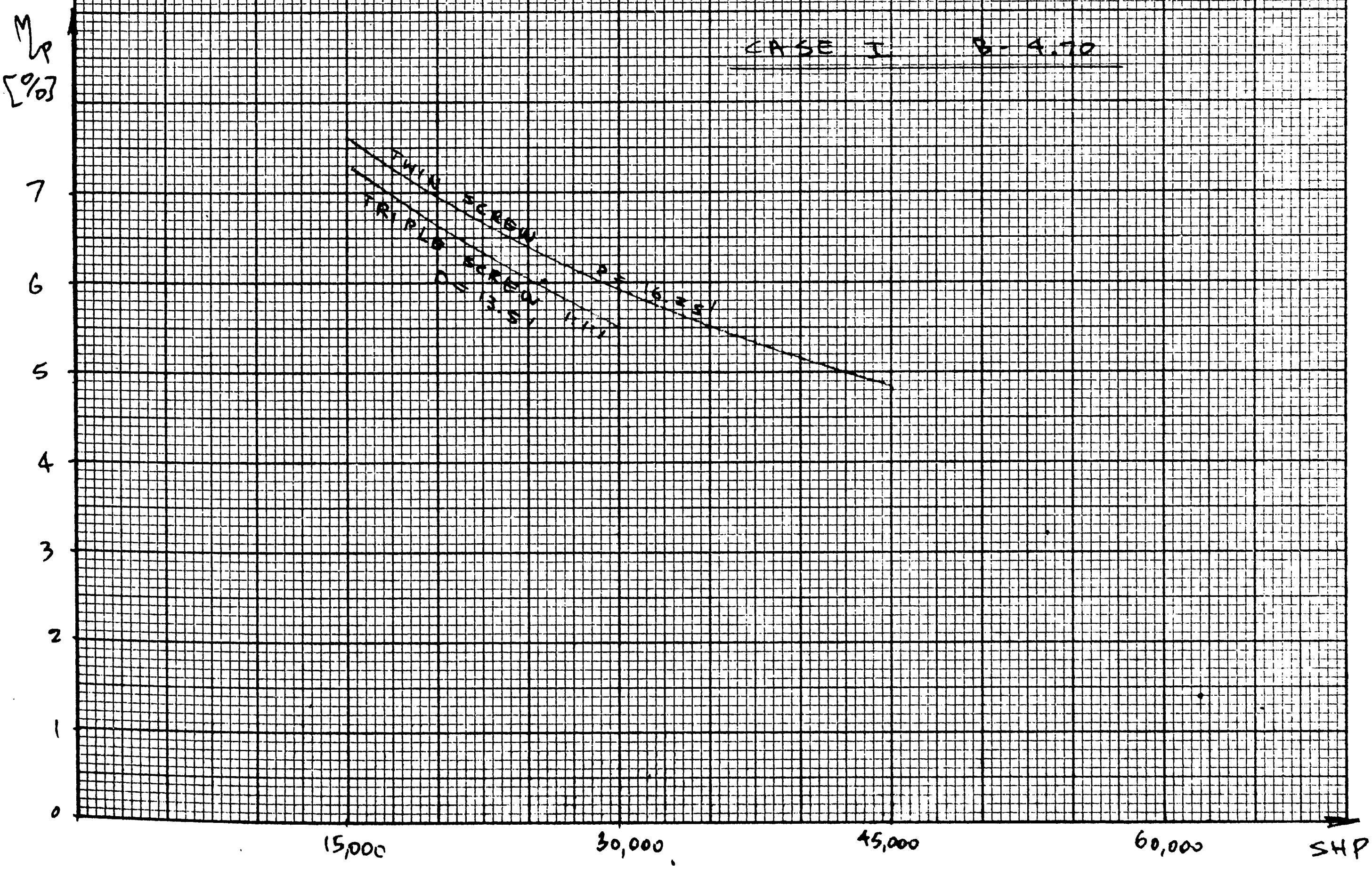


FIG 77 PROPULSIVE EFFICIENCY AT V_a OF 1 KNOT





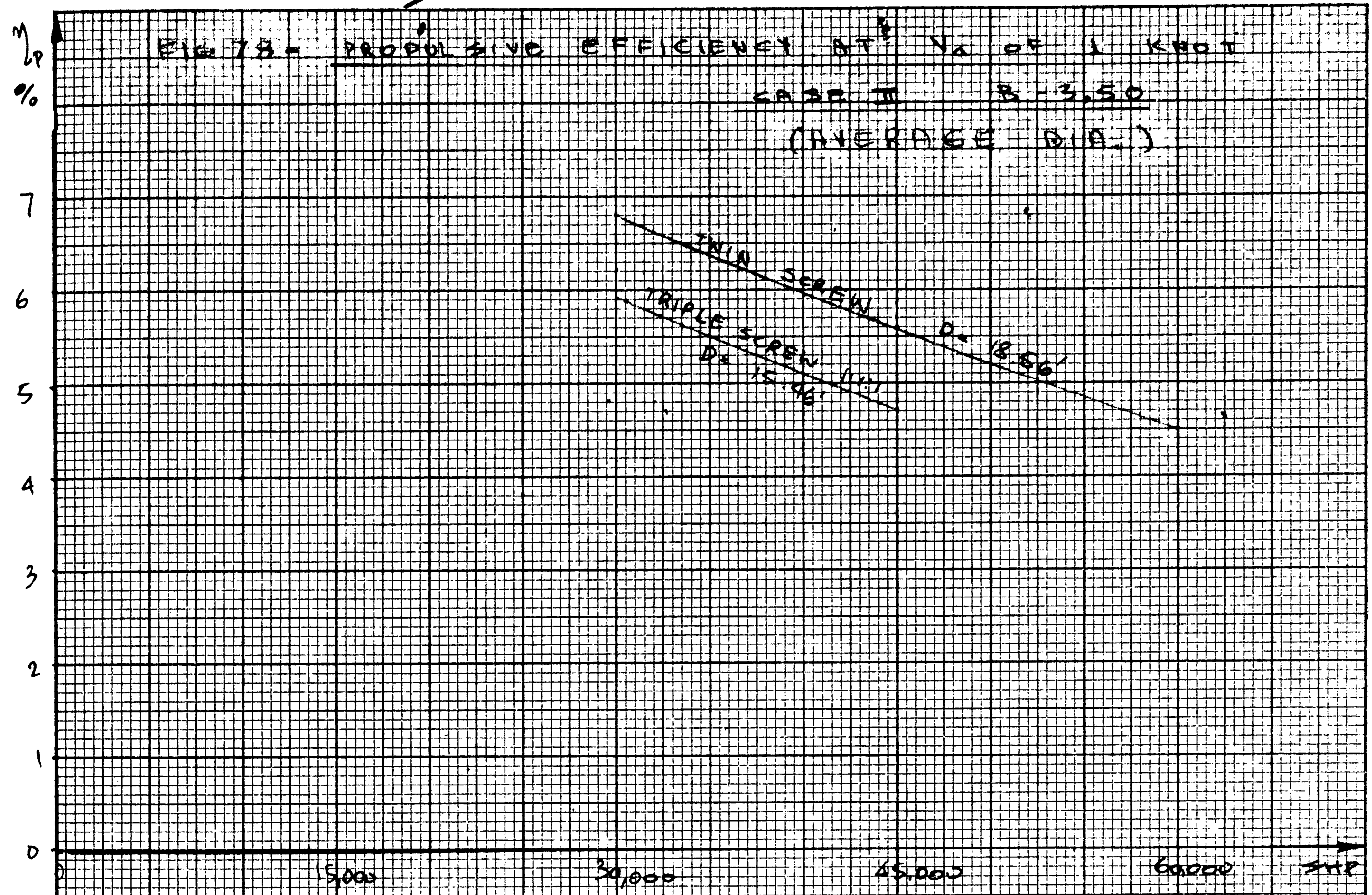
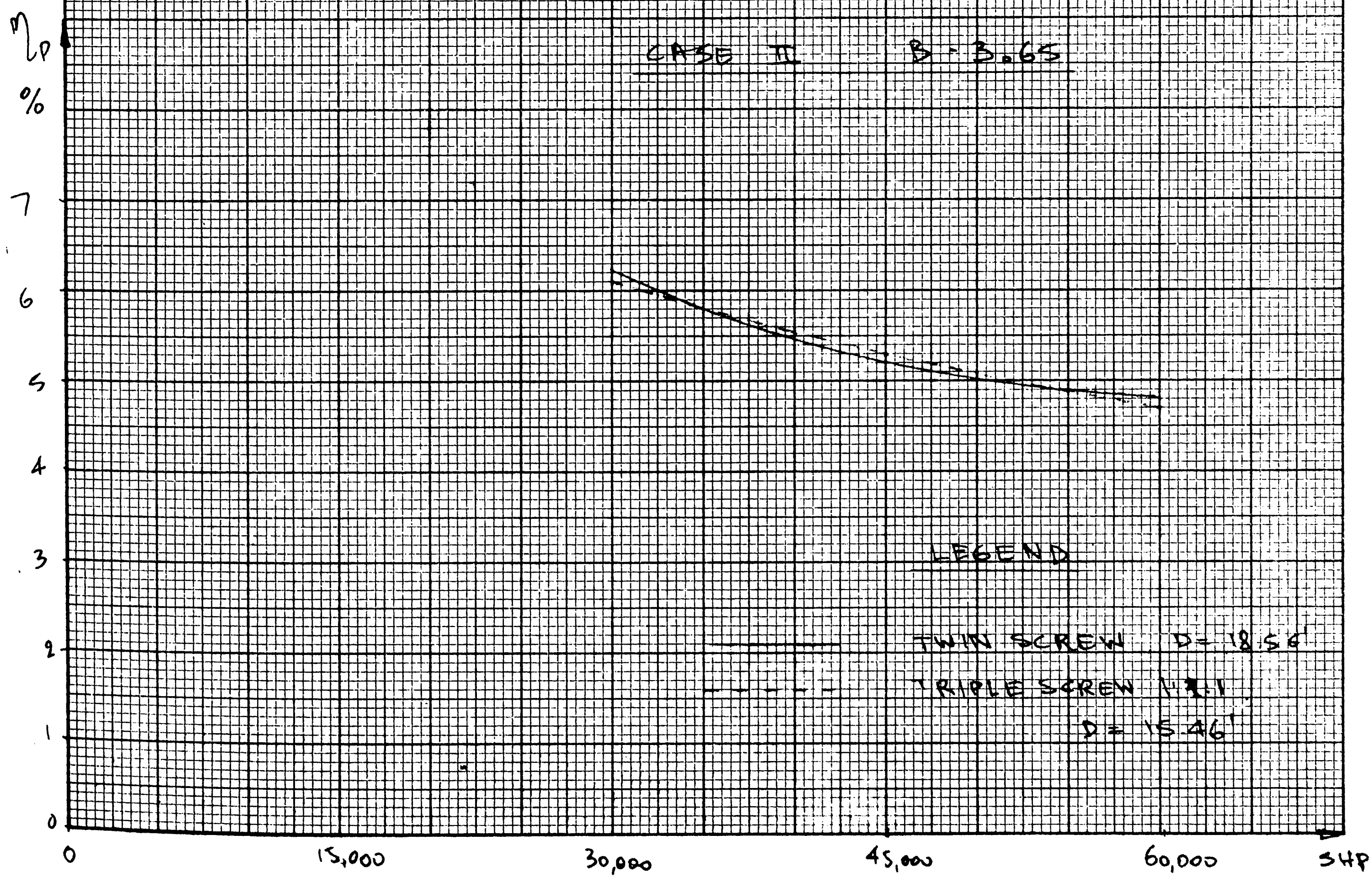


FIG 78 - PROPULSIVE EFFICIENCY AT Va OF 1 KNOT
CASE II B-3.50
(AVERAGE DIA.)
ηp %
TWIN SCREW D= 18.56'
TRIPLE SCREW 1:1:1 D= 15.46'
0
15,000
30,000
45,000
60,000
SHP


CASE II B-3.65
ηp %
LEGEND
TWIN SCREW D= 18.56'
TRIPLE SCREW 1:1:1
D= 15.46'
0
15,000
30,000
45,000
60,000
SHP

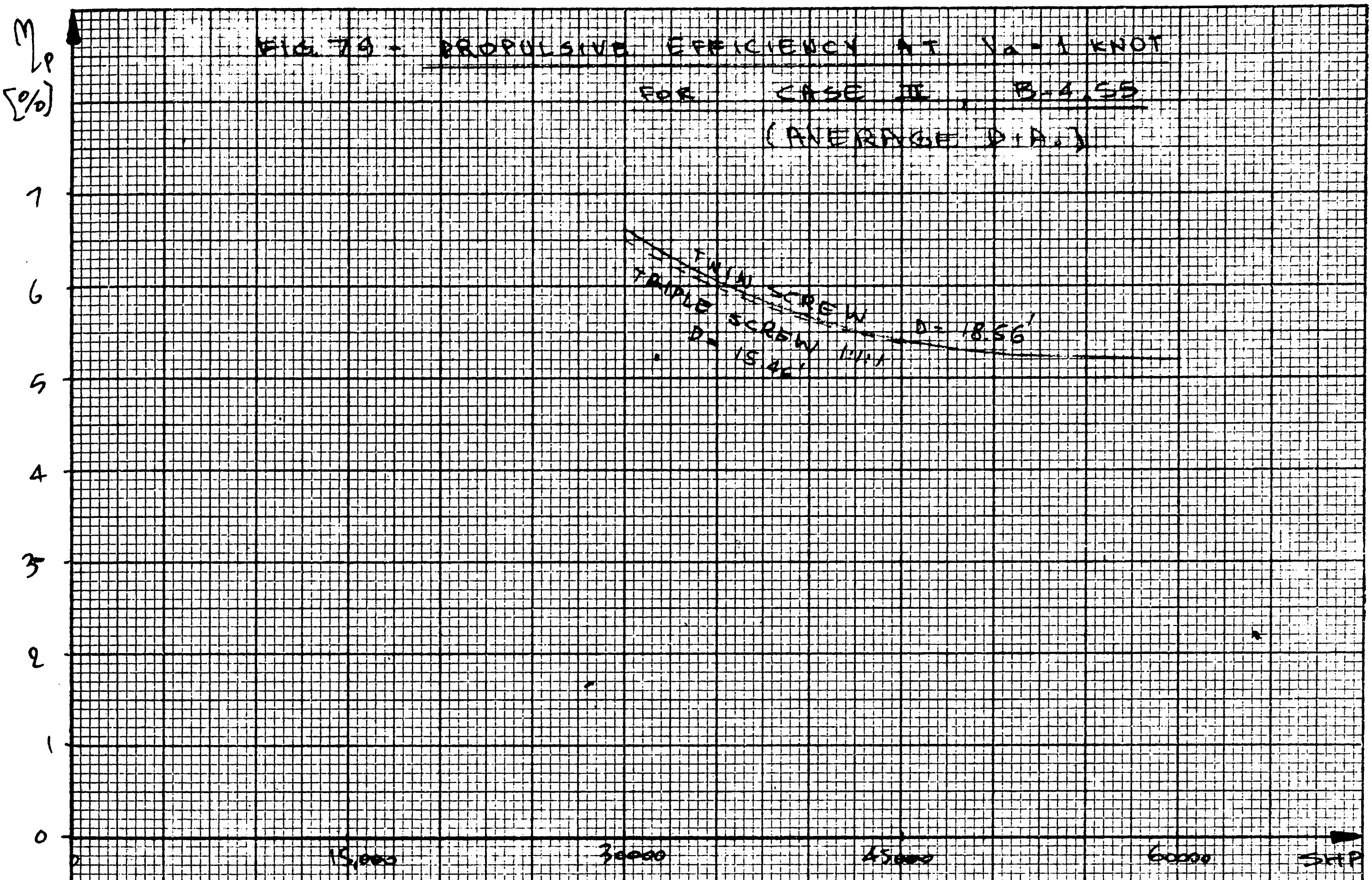


FIG. 79 - PROPULSIVE EFFICIENCY AT Va = 1 KNOT
FOR CASE II, B-4.55
(AVERAGE D.A.)
ηp [%]
TWIN SCREW D = 18.56'
TRIPLE SCREW 1:1:1 D = 15.46'
15,000
30000
45000
60000
SHP

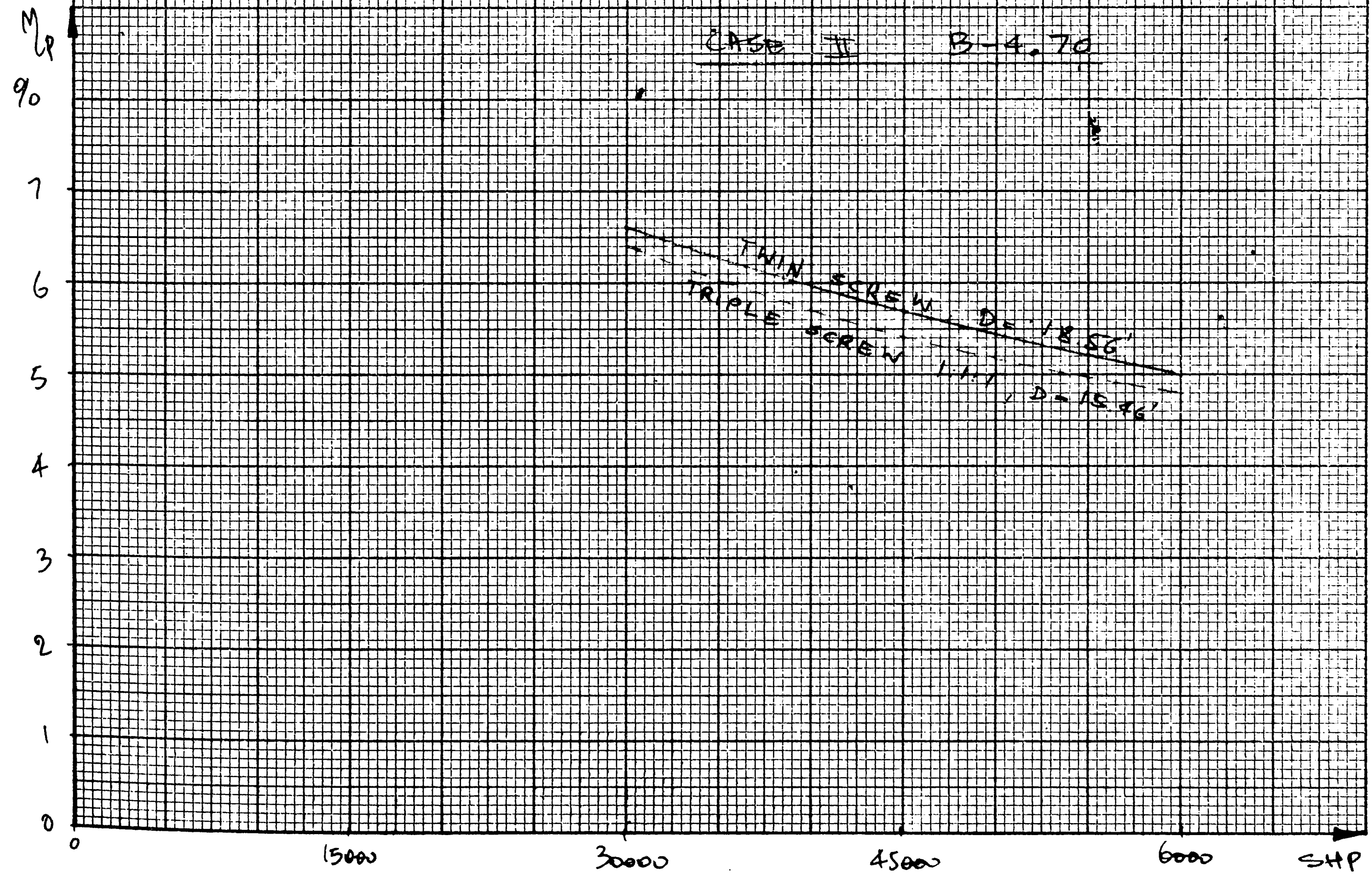
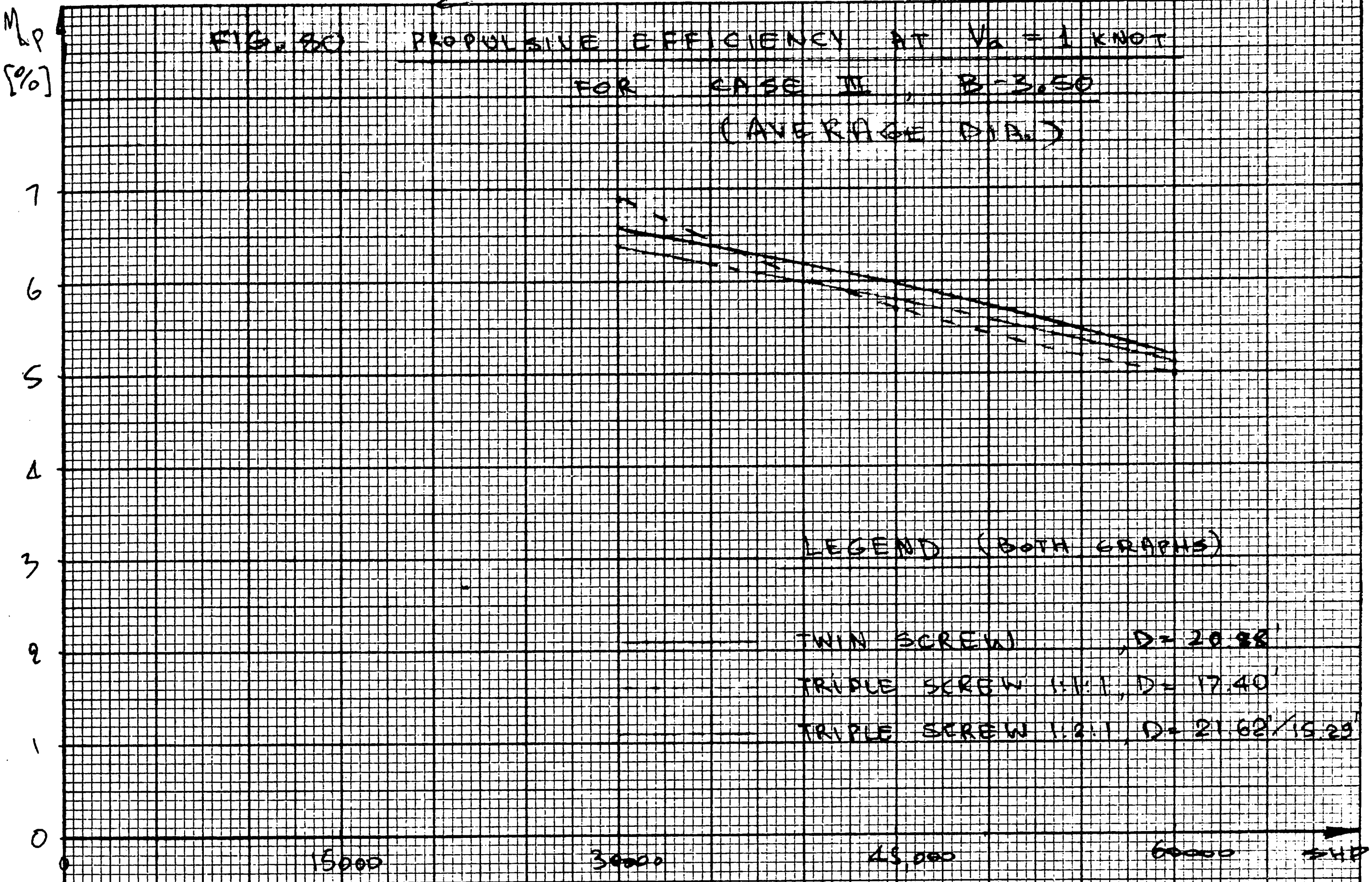

CASE II B-4.70
ηp %
TWIN SCREW D = 18.56'
TRIPLE SCREW 1:1:1 D = 15.46'
15000
30000
45000
60000
SHP

FIG. 80 PROPULSIVE EFFICIENCY AT V_a = 1 KNOT FOR CASE II, B-3.50 (AVERAGE DIA.)



CASE III, FOR B-3.65

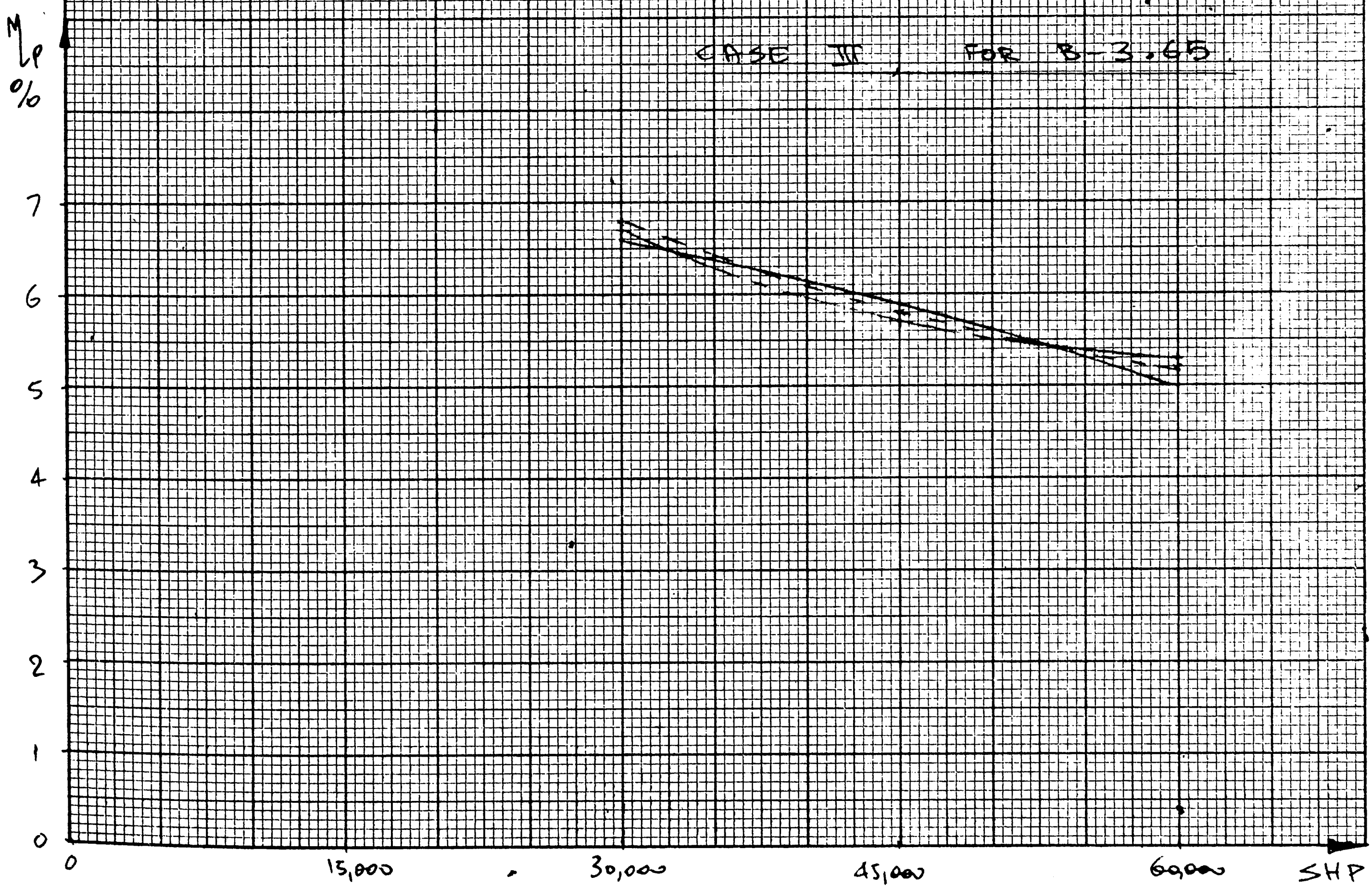
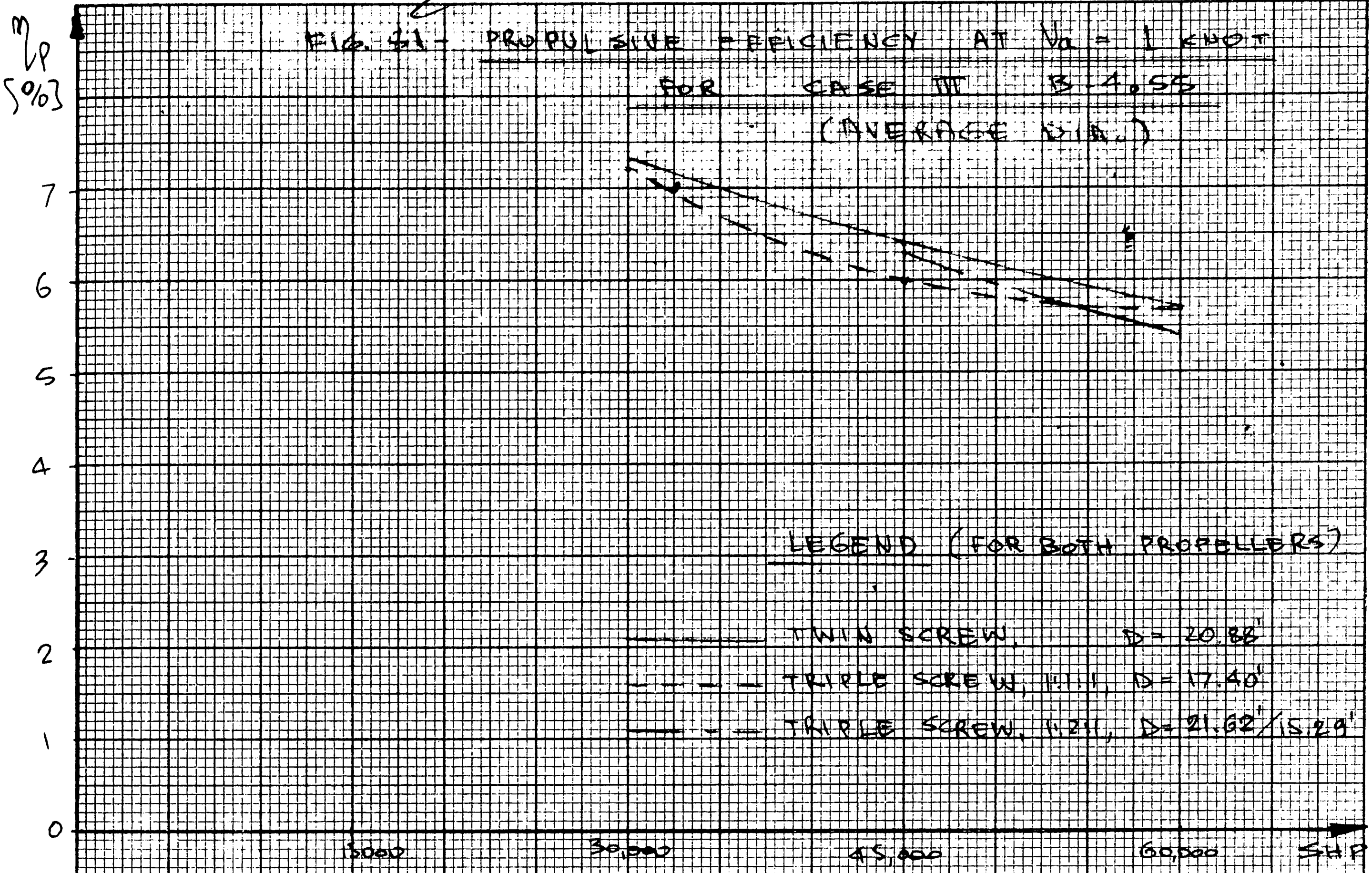


FIG. 21 - PROPULSIVE EFFICIENCY AT Va = 1 KNOT

FOR CASE III B-4.55

(AVERAGE DIA.)



FOR CASE III - B-4.70

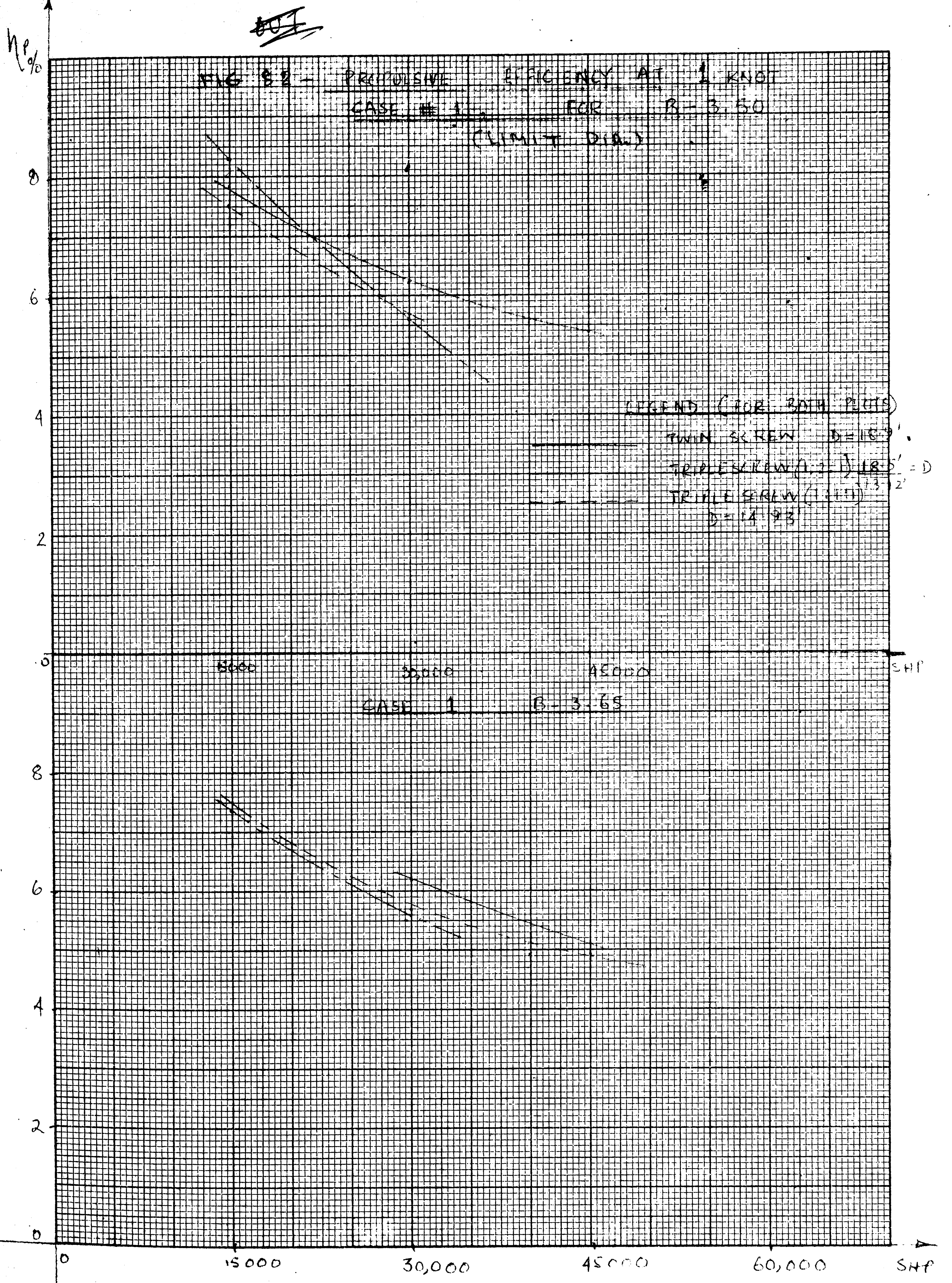


FIG 82 - PROPULSIVE EFFICIENCY AT 1 KNOT
CASE # 1 FOR B - 3.50
(LIMIT DIA.)
η_p %
8
6
4
2
0
15000
30,000
45000
SHP
LEGEND (FOR BOTH PLOTS)
TWIN SCREW D = 18.9'
TRIPLE SCREW (1:1:1) 18.5' = D
TRIPLE SCREW (1:1:1) D = 14.93
CASE 1 B - 3.65
8
6
4
2
0
15000
30,000
45000
60,000
SHP

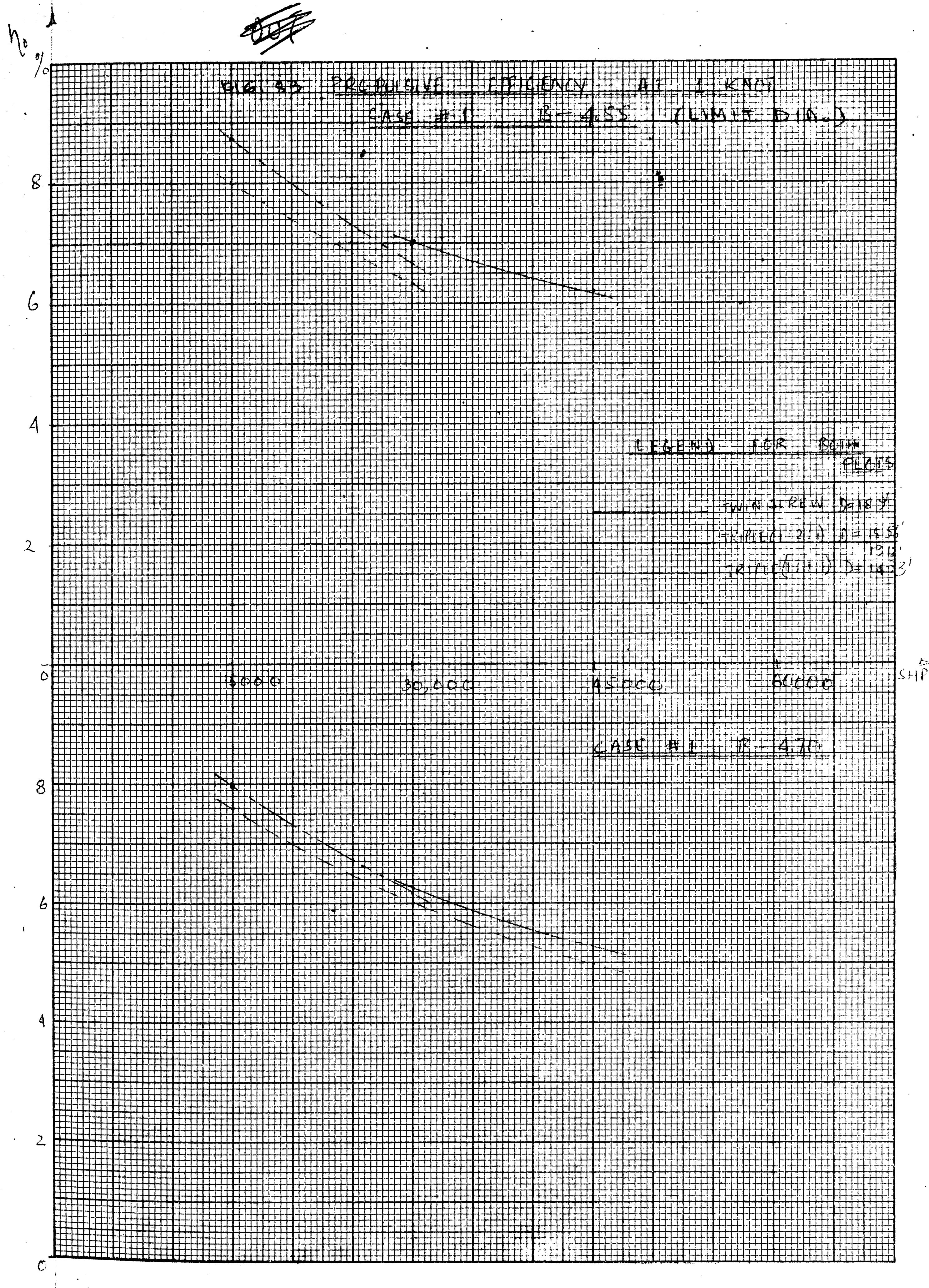


FIG. 33 PROPULSIVE EFFICIENCY AT 1 KNOT
CASE #1 B = 4.55 (LIMIT DIA.)
%
8
6
4
2
0
LEGEND FOR BOTH PLOTS
TWIN SCREW
30,000
45000
60000
SHP
CASE #1 B = 4.70
8
6
4
2
0

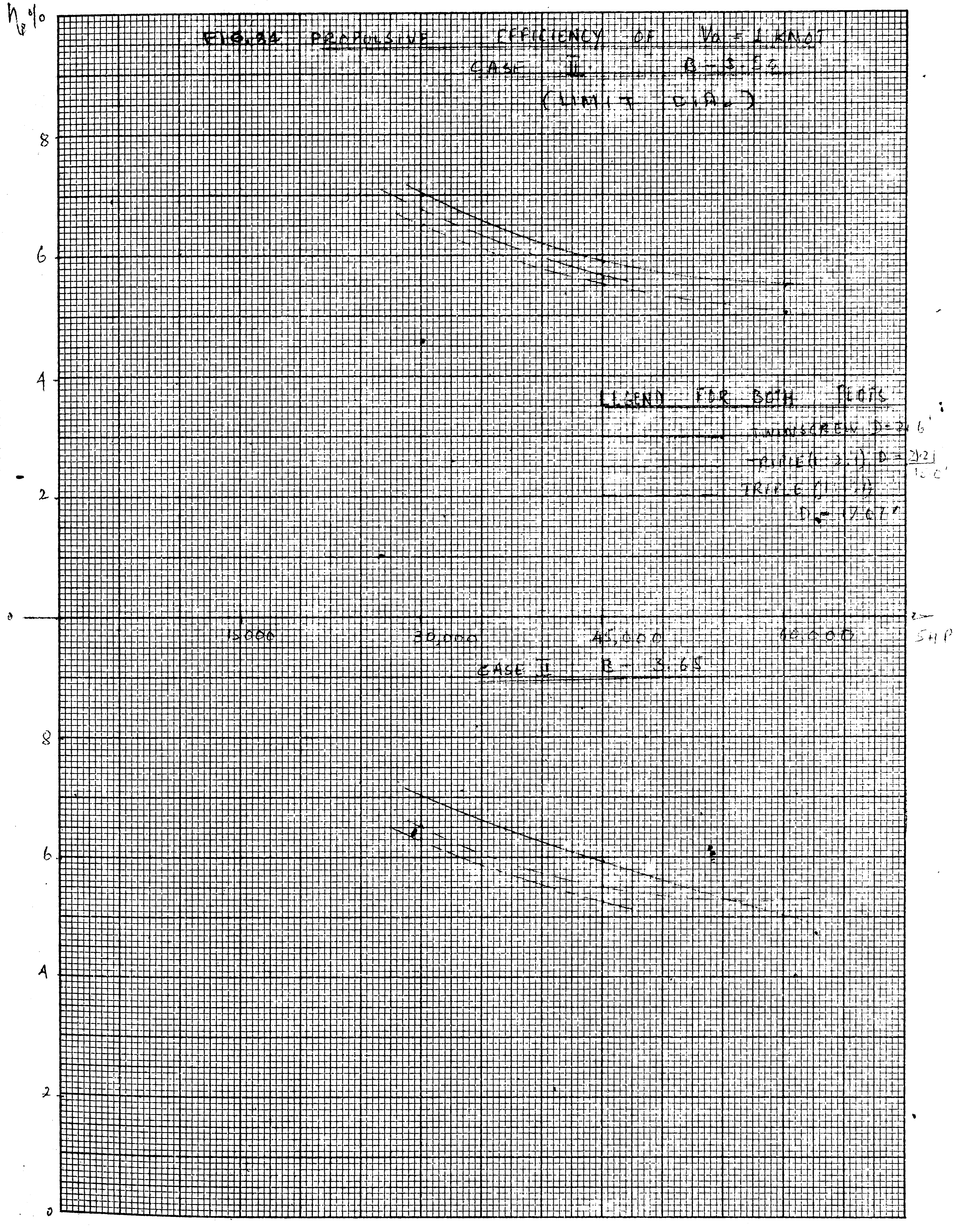


FIG. 34 PROPULSIVE EFFICIENCY OF Va = 1 KNOT
CASE II B = 3.52
(LIMIT DIA.)
LEGEND FOR BOTH PLOTS
TWINSCREW D = 21.6'
TRIPLE (1 : 2 : 1) D = 20.2'
TRIPLE (1 : 1 : 1) D = 17.67'
15000
30,000
45,000
60,000
SHP
CASE II B = 3.65
8
6
4
2
0

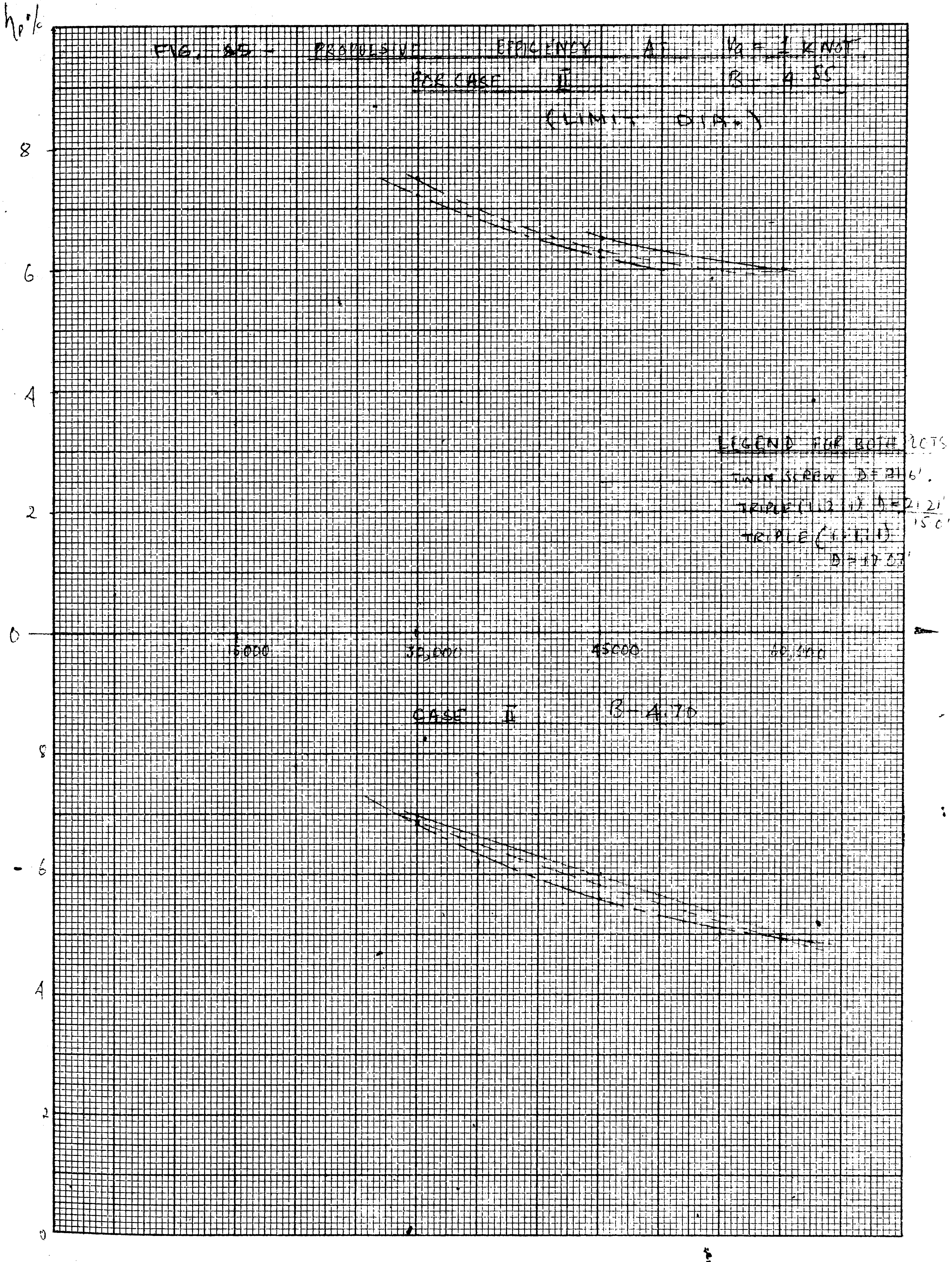
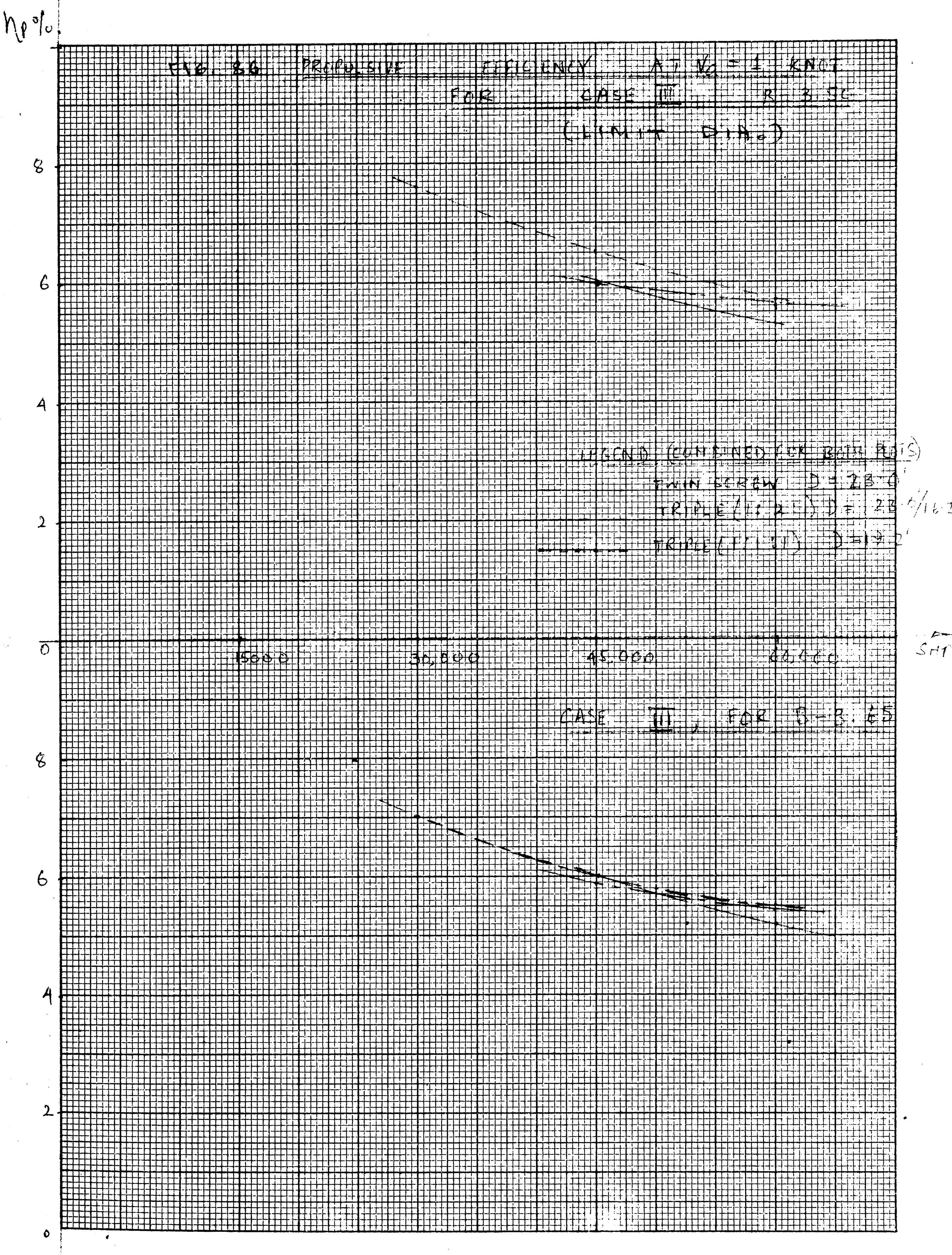
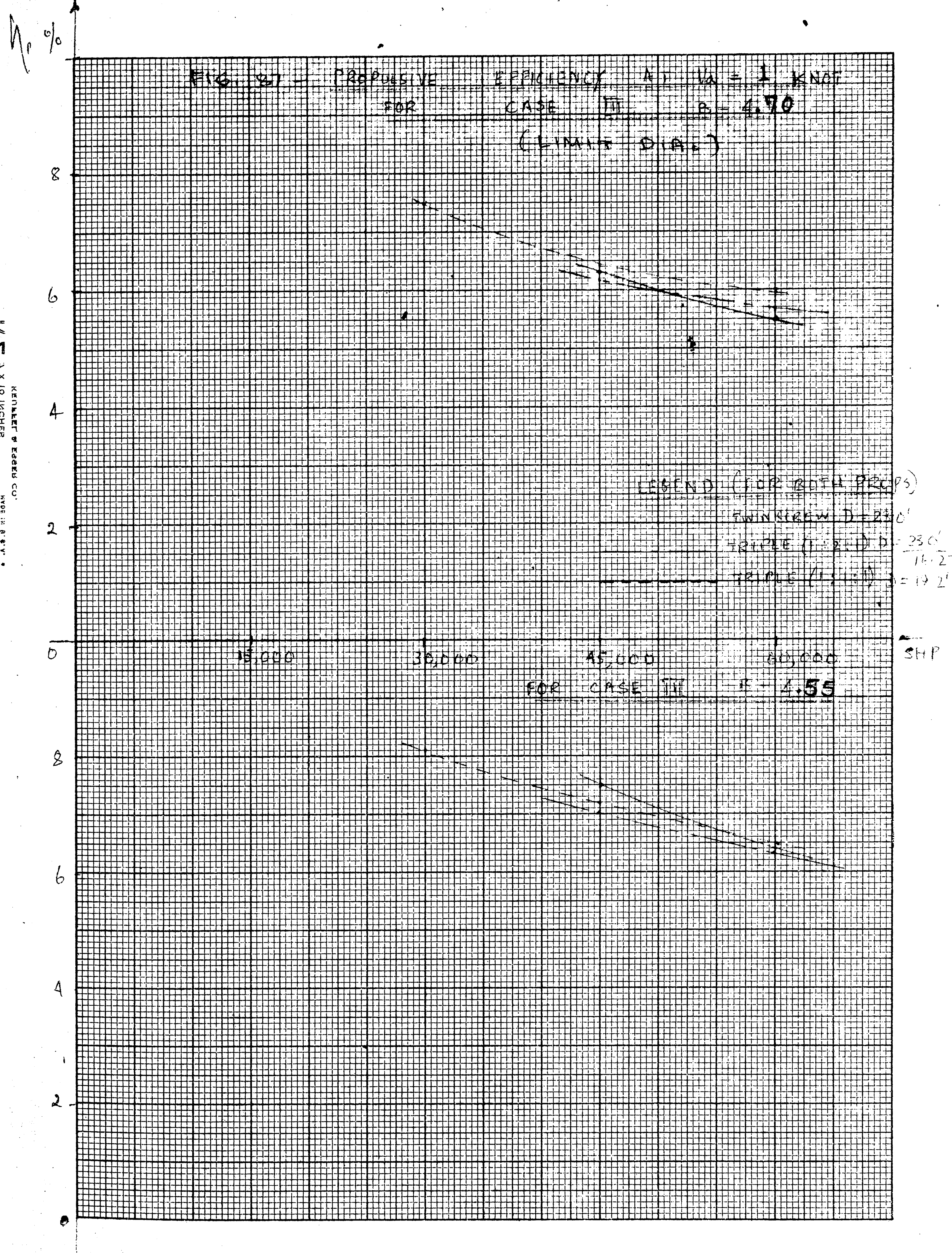


FIG. 85 - PROPULSIVE EFFICIENCY AT Va = 1 KNOT
FOR CASE II
B - 4.55
(LIMIT DIA.)
ηp %
8
6
4
2
0
15000
30,000
45000
60,000
CASE II
B - 4.70
LEGEND FOR BOTH PLOTS
TWIN SCREW D = 21.6'
TRIPLE (1:2:1) D = 21.21' / 15.0'
TRIPLE (1:1:1) D = 17.07'
8
6
4
2
0



ηp%
FIG. 26 PROPULSIVE EFFICIENCY AT Va = 1 KNOT
FOR CASE III B 3.50
(LIMIT DIA.)
LEGEND (COMBINED FOR BOTH B'S)
TWIN SCREW D = 28.0'
TRIPLE (1:2) D = 28.9/16'
TRIPLE (1:1.1) D = 19.2'
8
6
4
2
0
15000
30,000
45,000
60,000
SHP
CASE III, FOR B = 3.65
8
6
4
2
0



η_p %
FIG. 87 — PROPULSIVE EFFICIENCY AT Va = 1 KNOT
FOR CASE III R = 4.70
(LIMIT DIA.)
8
6
4
2
0
15,000
30,000
45,000
60,000
SHP
FOR CASE III R = 4.55
LEGEND (FOR BOTH PROPS)
TWIN SCREW D = 23.0'
TRIPLE (1:2:1) D = 23.0' / 16.27
TRIPLE (1:1:1) D = 19.2'

OUT

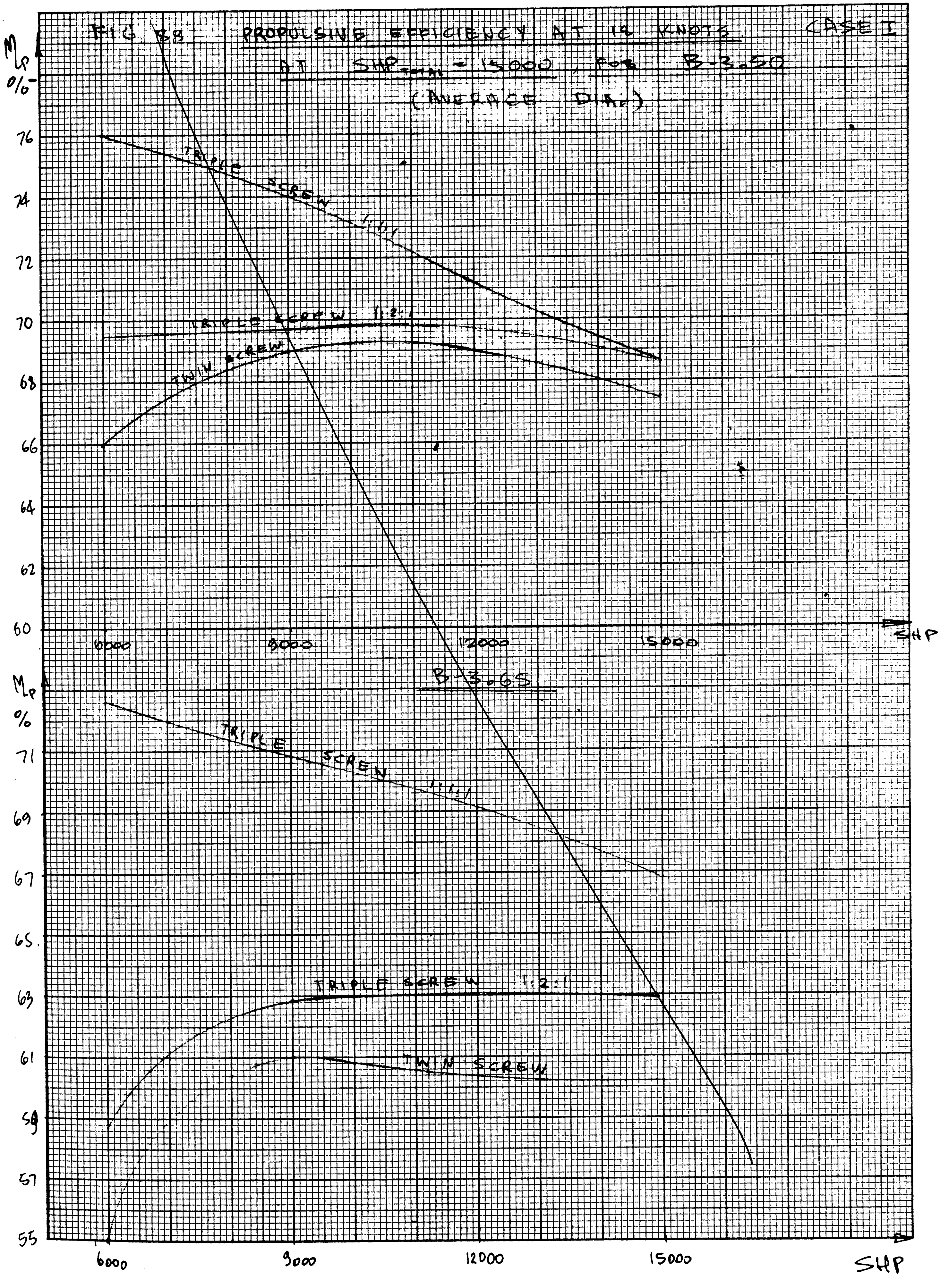


FIG 38 PROPULSIVE EFFICIENCY AT 12 KNOTS
CASE I
AT SHP total = 15000, FOR B-3.50
(AVERAGE DIA.)
η_P %
76
74
72
70
68
66
64
62
60
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:2:1
TWIN SCREW
6000
9000
12000
15000
SHP
B-3.65
η_P %
71
69
67
65
63
61
59
57
55
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:2:1
TWIN SCREW
6000
9000
12000
15000
SHP

OUT

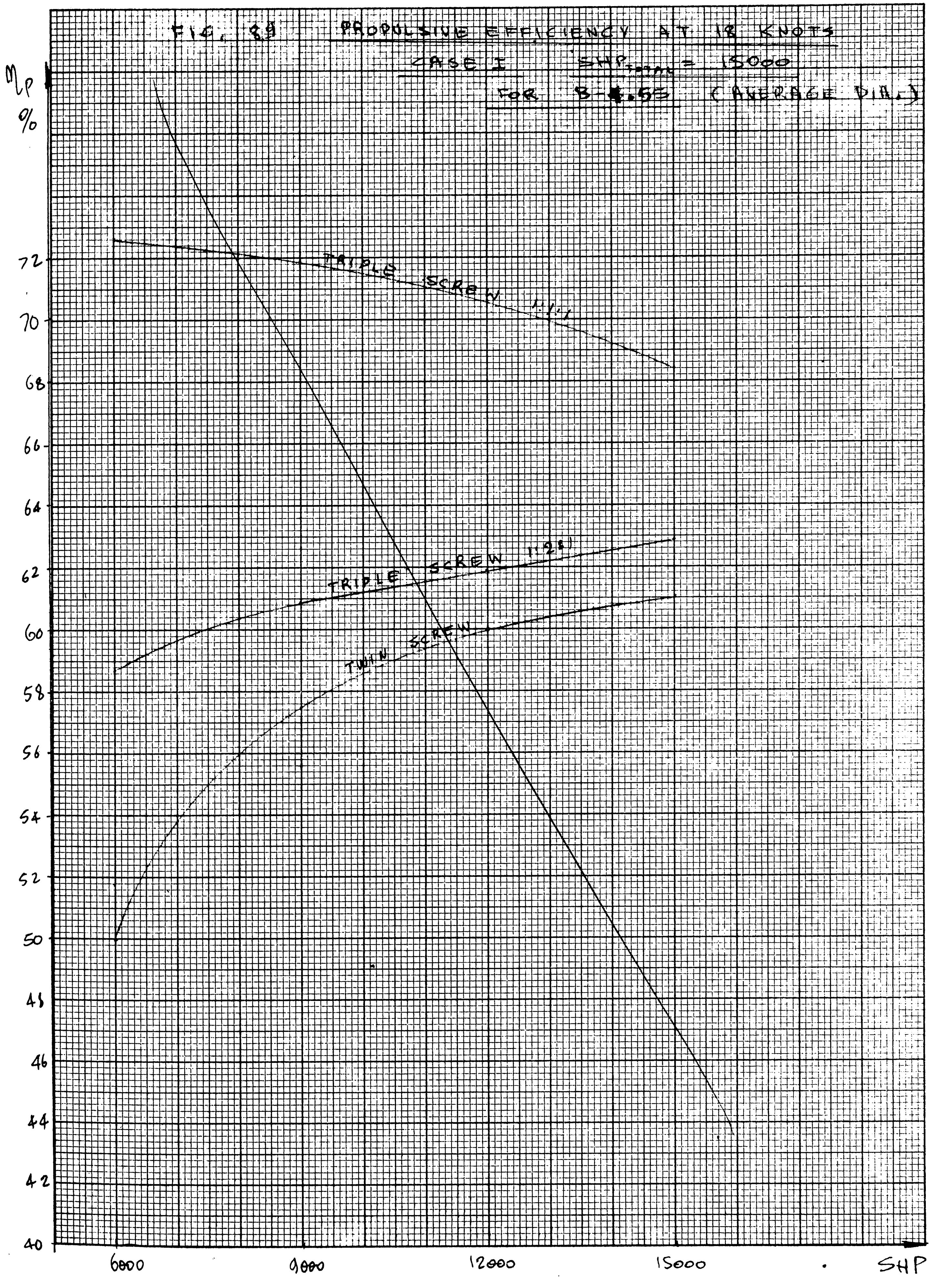


FIG. 89 PROPULSIVE EFFICIENCY AT 18 KNOTS

CASE I SHP$_{TOTAL}$ = 15000

FOR B-4.55 (AVERAGE DIA.)

OUT.

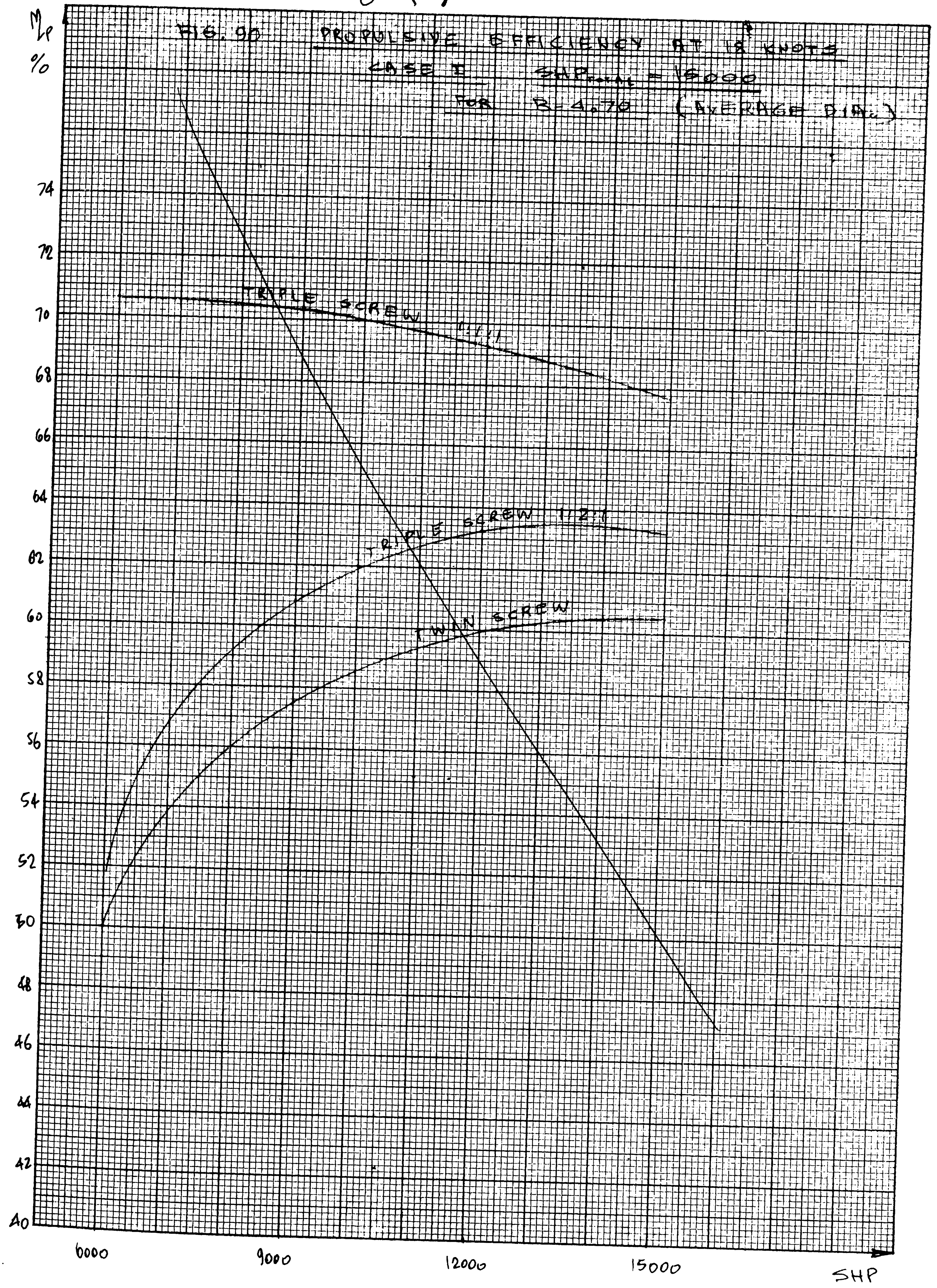


FIG. 90 PROPULSIVE EFFICIENCY AT 18 KNOTS
CASE II SHP TOTAL = 15000
FOR B-4.70 (AVERAGE DIA.)
η_P %
74
72
70
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:2:1
TWIN SCREW
6000
9000
12000
15000
SHP

OUT

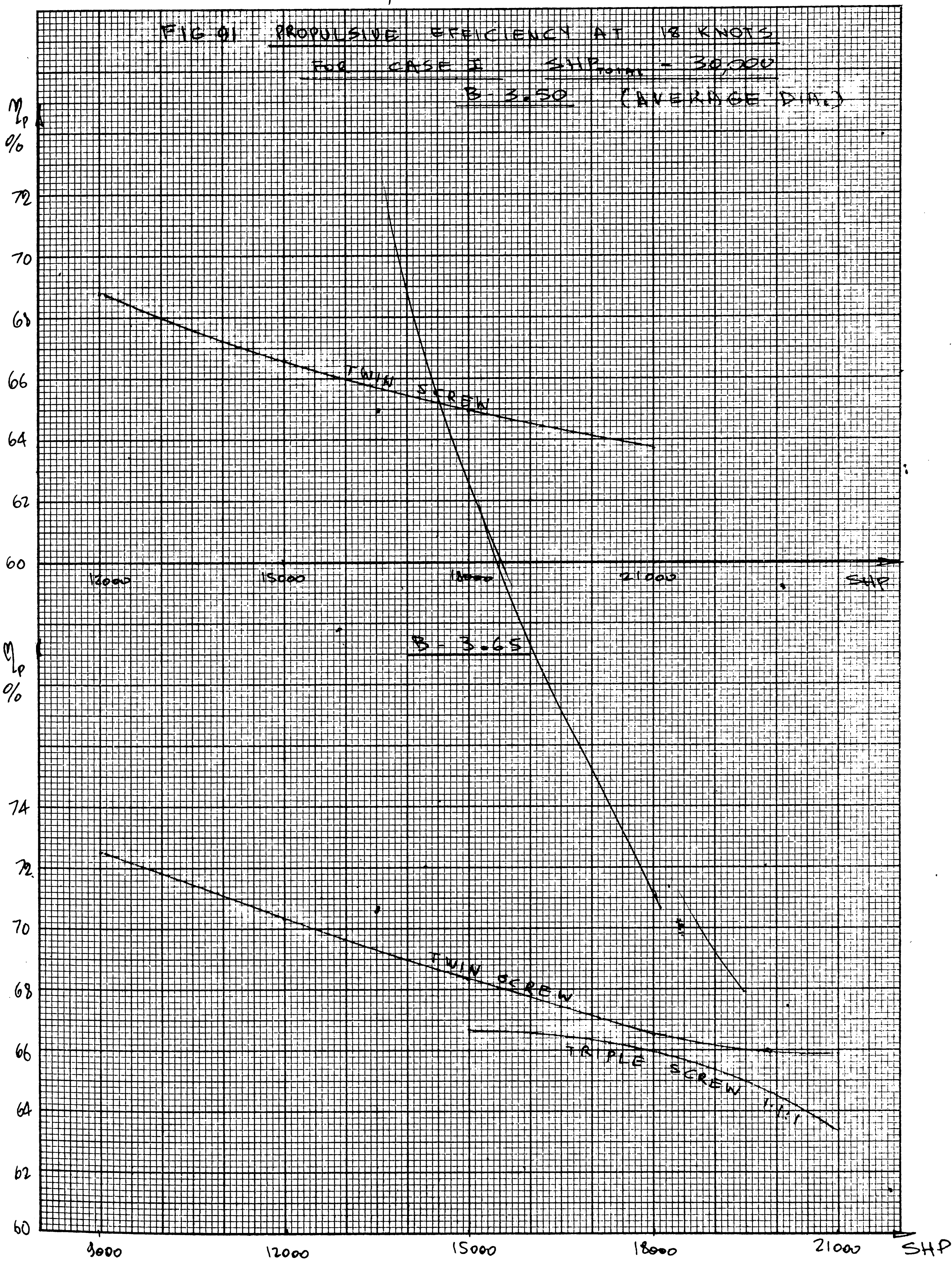
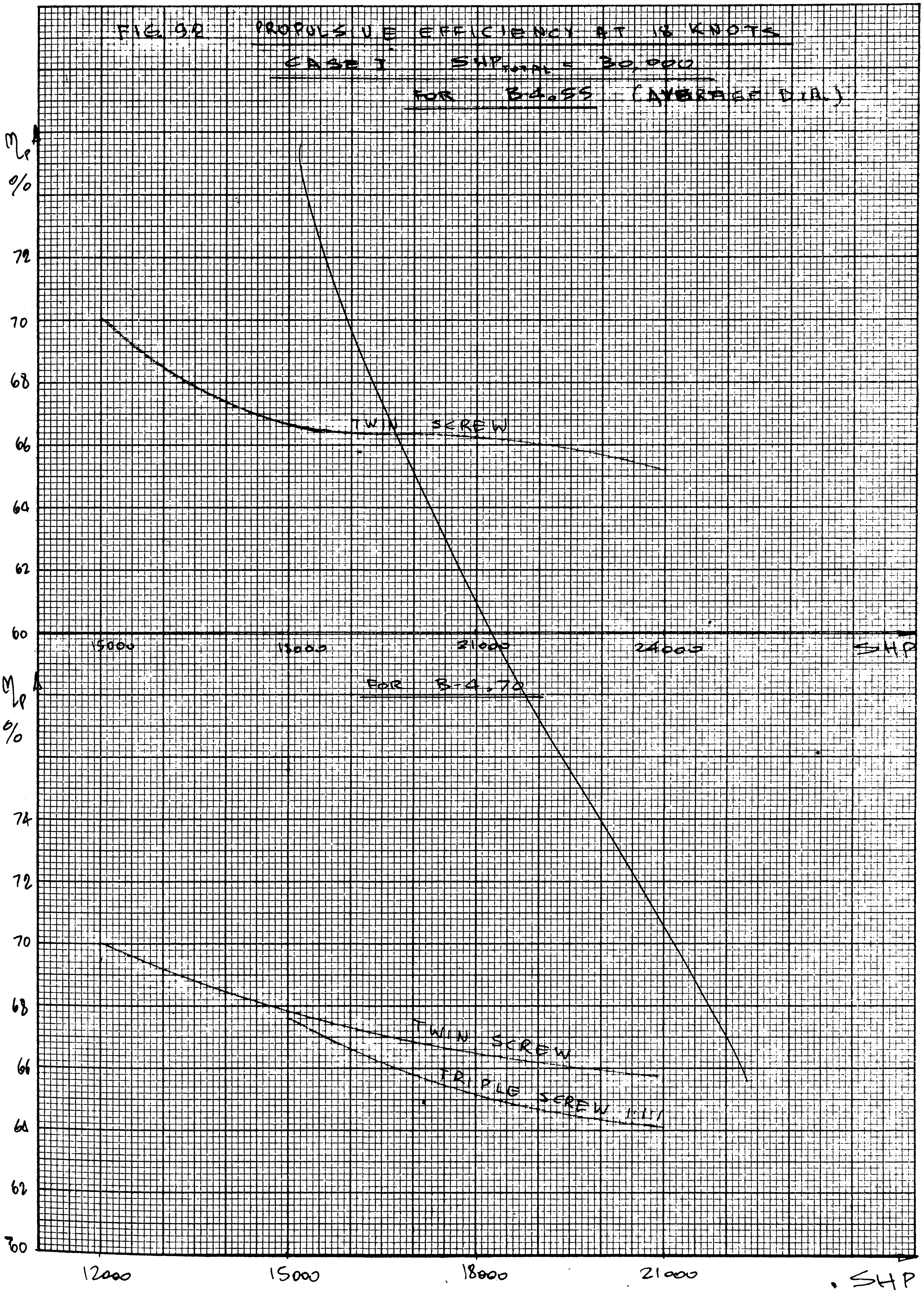


FIG 91 PROPULSIVE EFFICIENCY AT 18 KNOTS
FOR CASE I SHP TOTAL = 30,000
B 3.50 (AVERAGE DIA.)
ηp %
72
70
68
66
64
62
60
12000
15000
18000
21000
SHP
TWIN SCREW
B 3.65
ηp %
74
72
70
68
66
64
62
60
9000
12000
15000
18000
21000
SHP
TWIN SCREW
TRIPLE SCREW 1:1:1

OUT

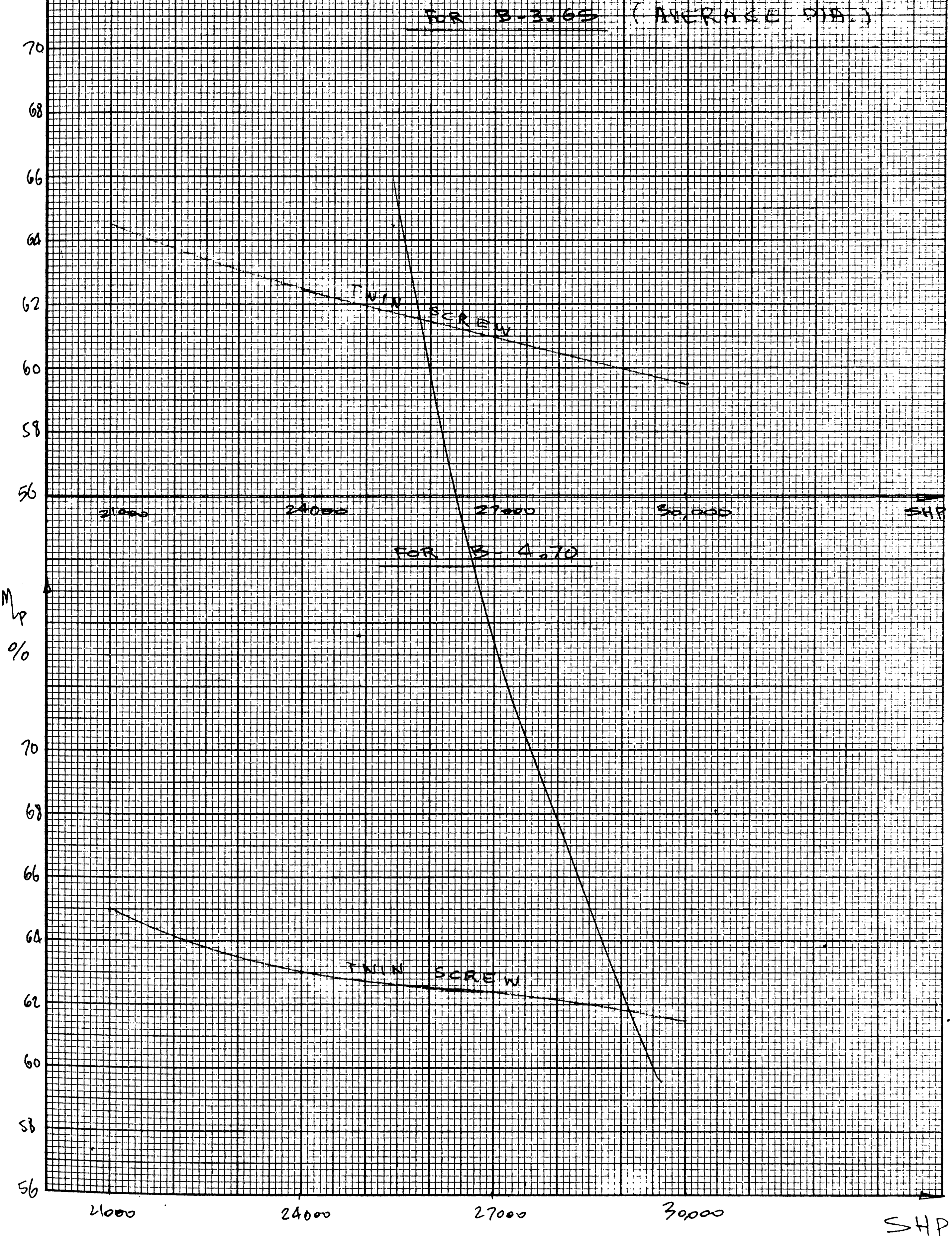
FIG. 92 PROPULSIVE EFFICIENCY AT 18 KNOTS

CASE I SHP$_{TOTAL}$ = 30,000



OUT

FIG 93 PROPULSIVE EFFICIENCY AT 18 KNOTS
CASE I SHP total = 45,000



OUT

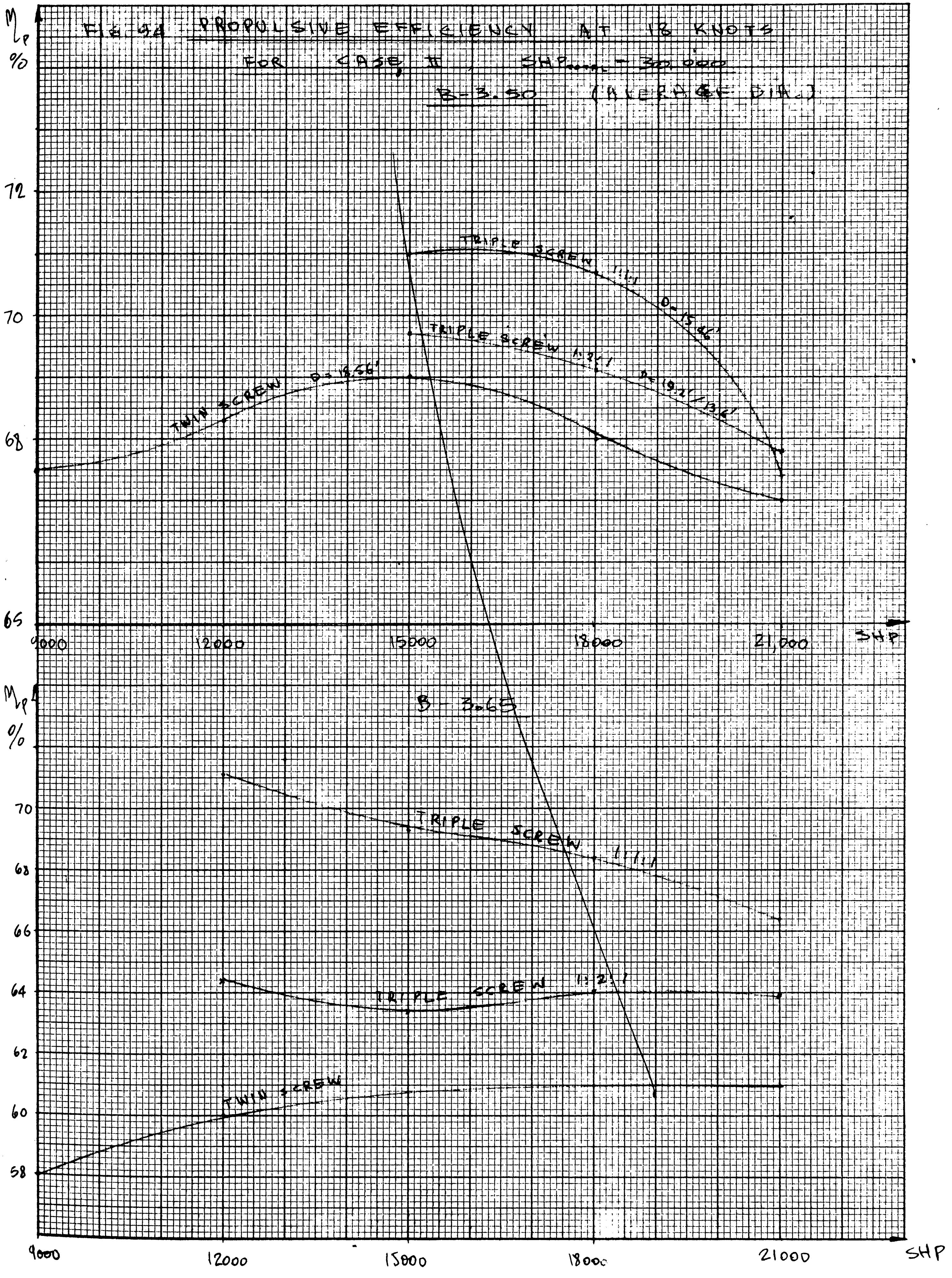


FIG. 94 PROPULSIVE EFFICIENCY AT 18 KNOTS
FOR CASE II, SHP = 30,000
B-3.50 (AVERAGE DIA.)
η_p %
72
70
68
65
TRIPLE SCREW 1:1:1
D=15.46'
TRIPLE SCREW 1:2:1
D=19.2'/13.6'
TWIN SCREW D=18.66'
9000
12000
15000
18000
21,000
SHP
B-3.65
η_p %
70
68
66
64
62
60
58
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:2:1
TWIN SCREW
9000
12000
15000
18000
21000
SHP

OUT

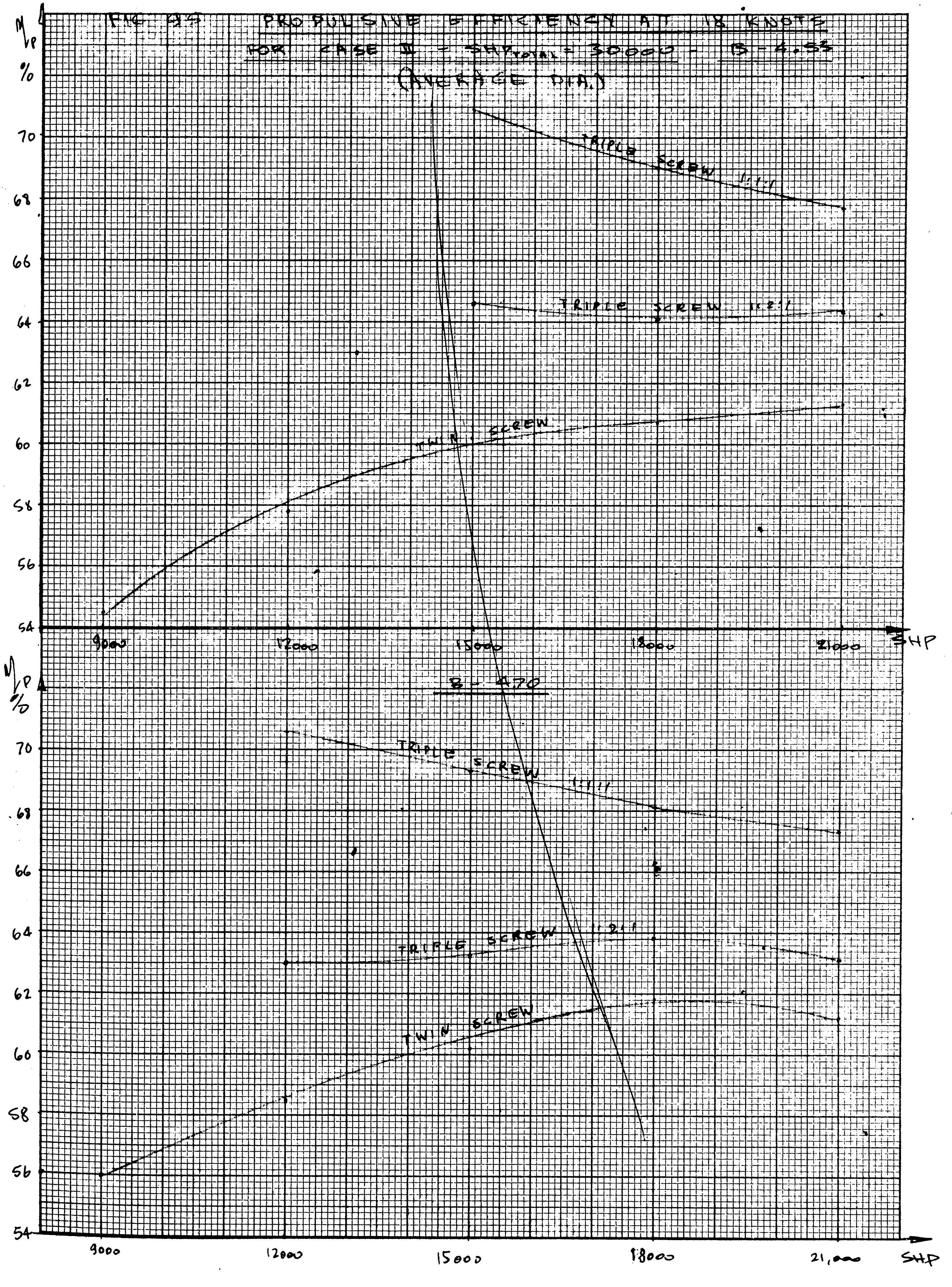


FIG 93
PROPULSIVE EFFICIENCY AT 18 KNOTS
FOR CASE II - SHP TOTAL = 30000 - B-4.53
(AVERAGE DIA.)
η_P %
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:2:1
TWIN SCREW
SHP
B-4.70
9000
12000
15000
18000
21000
54
56
58
60
62
64
66
68
70

OUT

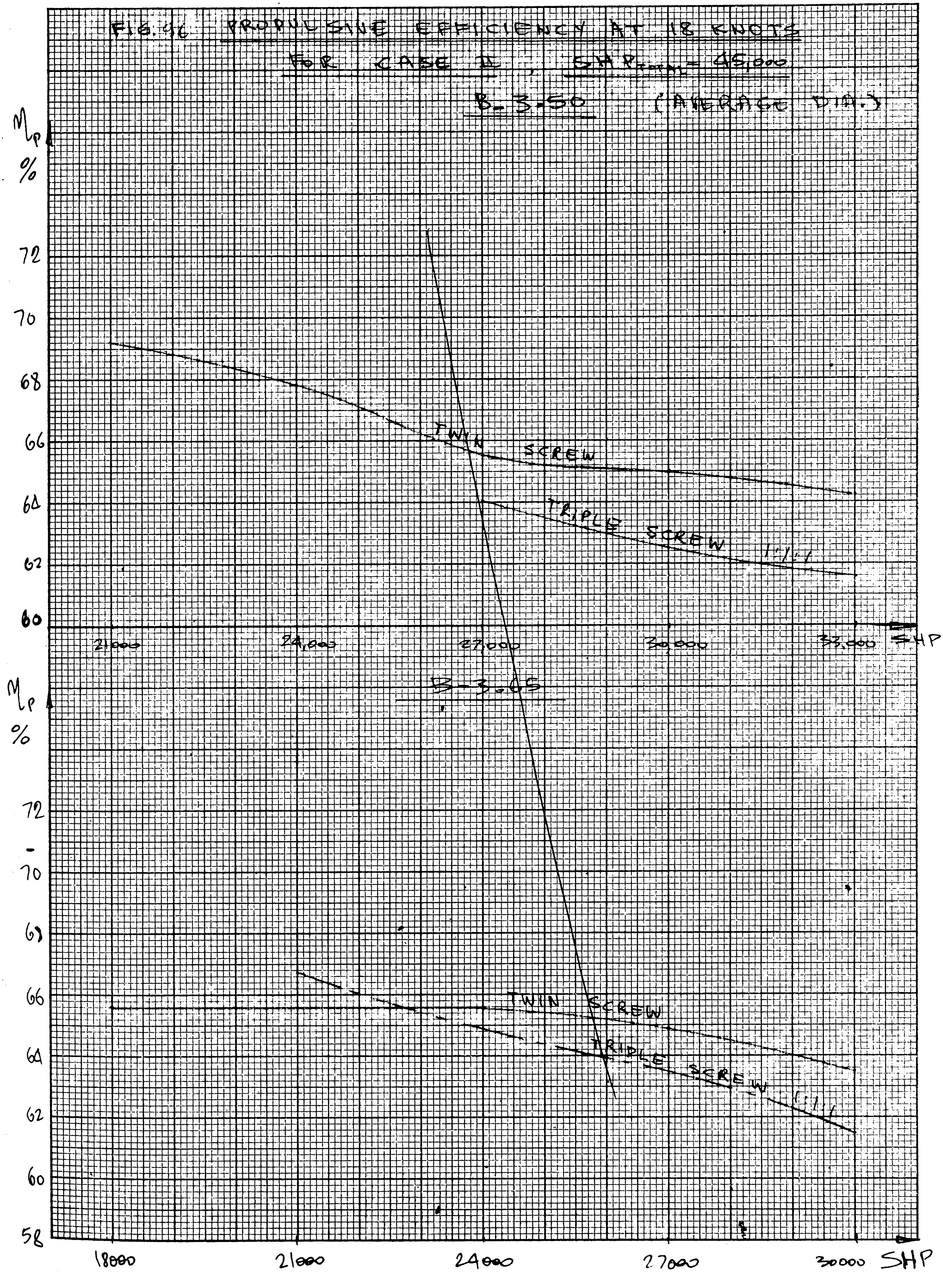


FIG. 46 PROPULSIVE EFFICIENCY AT 18 KNOTS
FOR CASE II, SHP TOTAL = 45,000
B-3.50 (AVERAGE DIA.)
η_P %
72
70
68
66
64
62
60
TWIN SCREW
TRIPLE SCREW
1:1:1
21,000
24,000
27,000
30,000
33,000
SHP
B-3.65
η_P %
72
70
68
66
64
62
60
58
TWIN SCREW
TRIPLE SCREW
1:1:1
18000
21000
24000
27000
30000
SHP

OUT

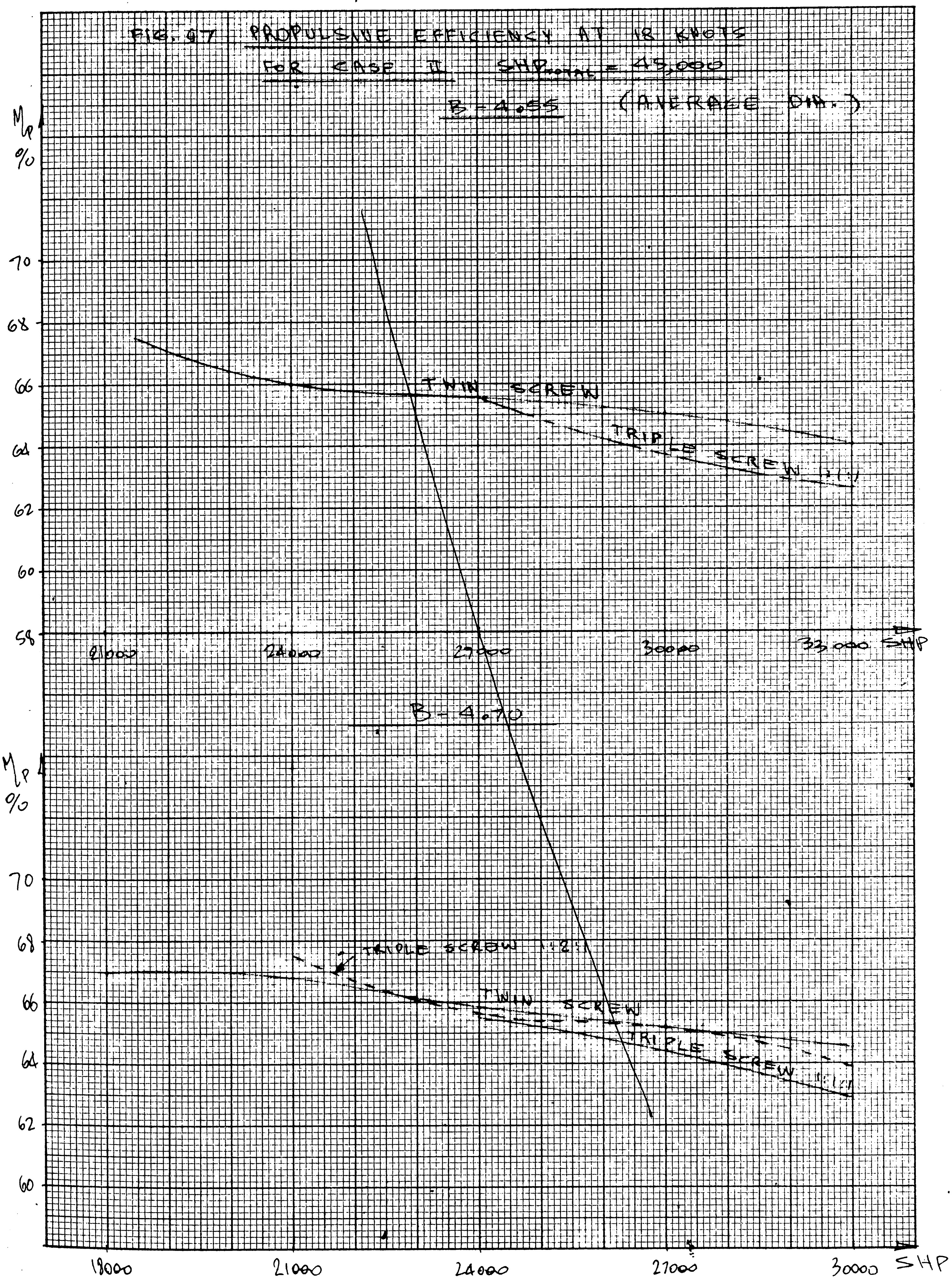


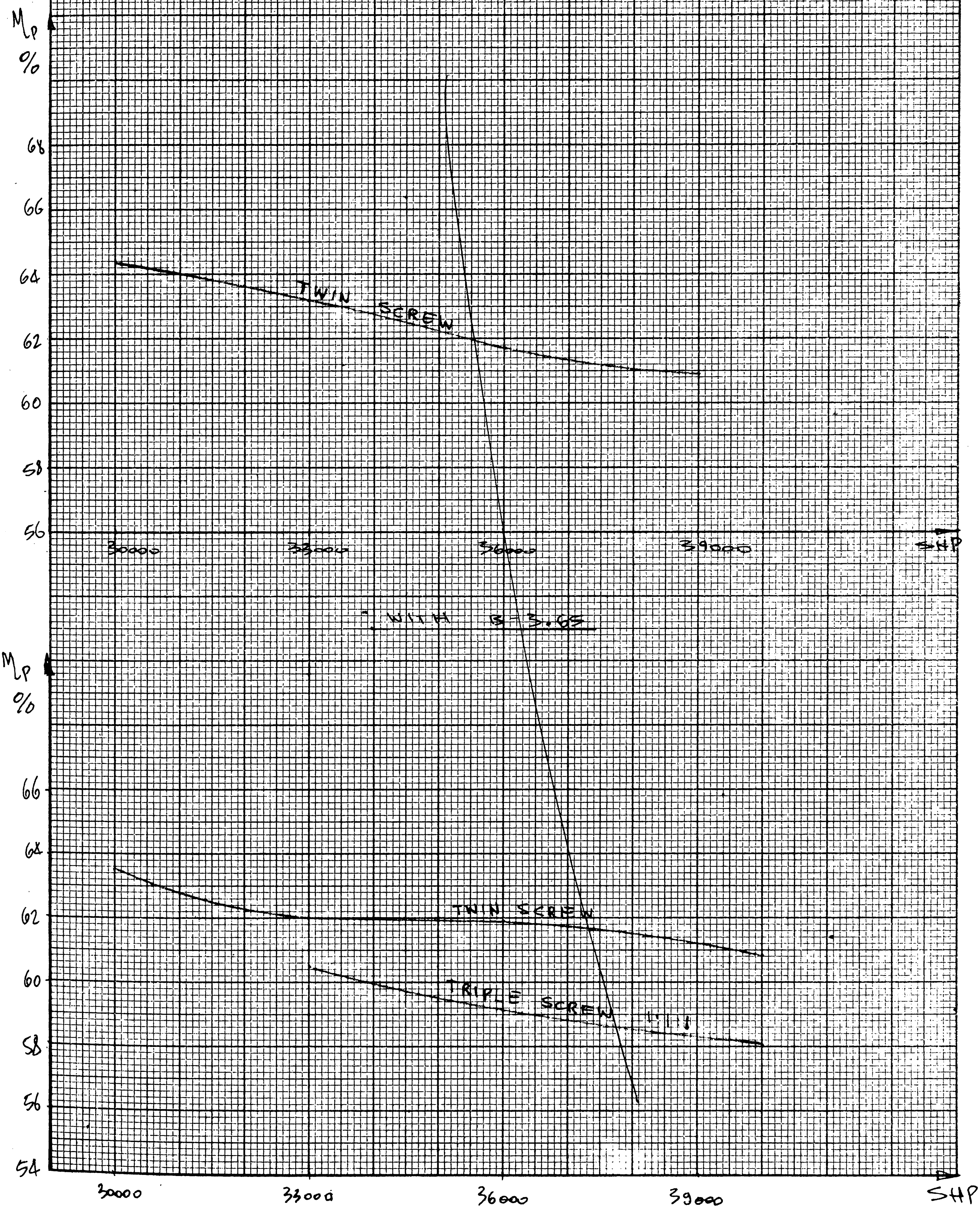
FIG. 47 PROPULSIVE EFFICIENCY AT 18 KNOTS
FOR CASE II SHP TOTAL = 45,000
B = 4.55 (AVERAGE DIA.)
ηp %
70
68
66
64
62
60
58
TWIN SCREW
TRIPLE SCREW 1:1
21000
24000
27000
30000
33,000 SHP
B = 4.70
ηp %
70
68
66
64
62
60
TRIPLE SCREW 1:2:1
TWIN SCREW
TRIPLE SCREW 1:1:1
18000
21000
24000
27000
30000 SHP

OUT

FIG. 92 – PROPULSIVE EFFICIENCY AT 18 KNOTS

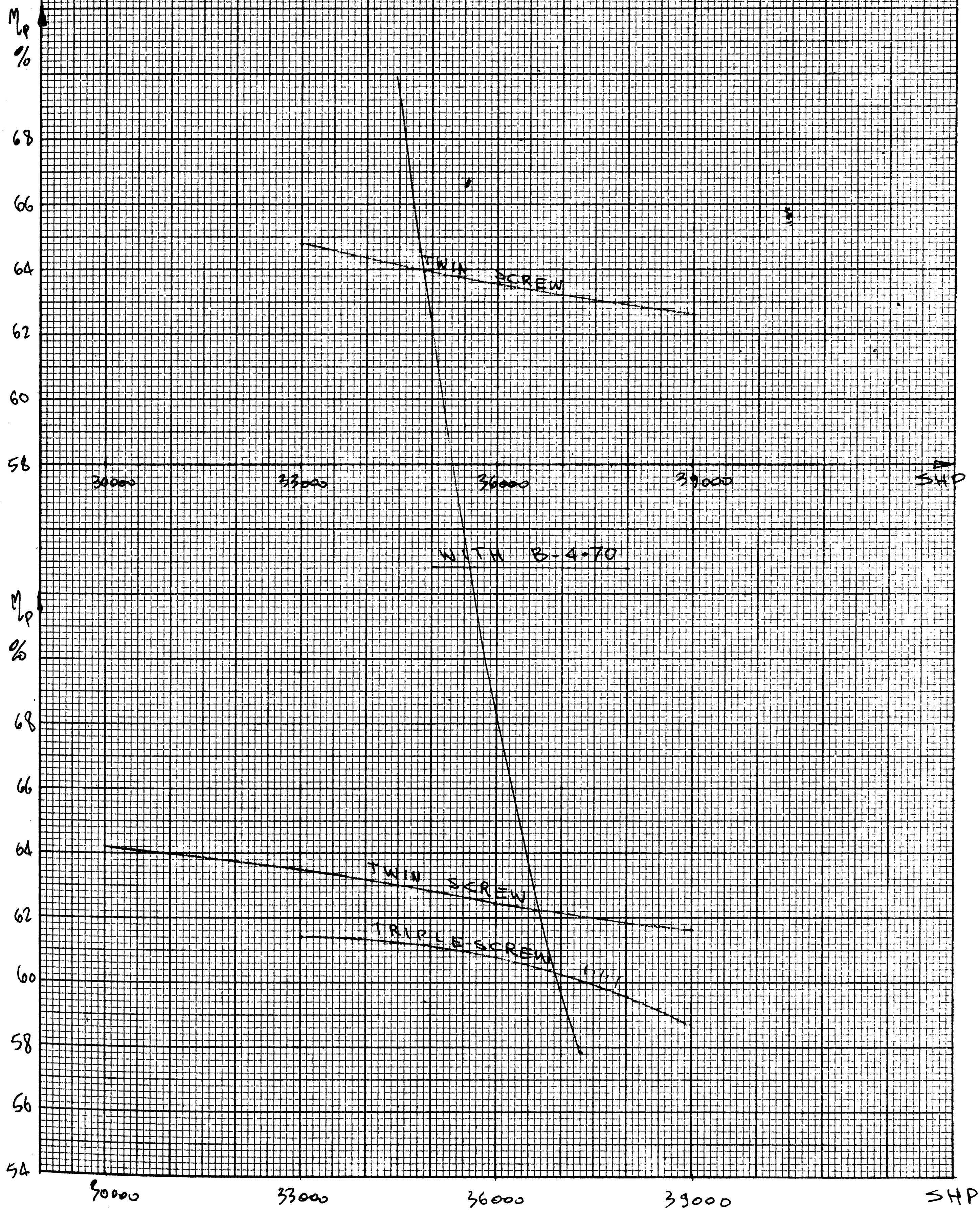
FOR CASE II SHP_TOTAL = 60,000

WITH B-3.50 (AVERAGE DIA.)



OUT

FIG. 99 - PROPULSIVE EFFICIENCY AT 18 KNOTS
FOR CASE II SHP$_{TOTAL}$ = 60000
WITH B-4-65 (AVERAGE DIA.)



007

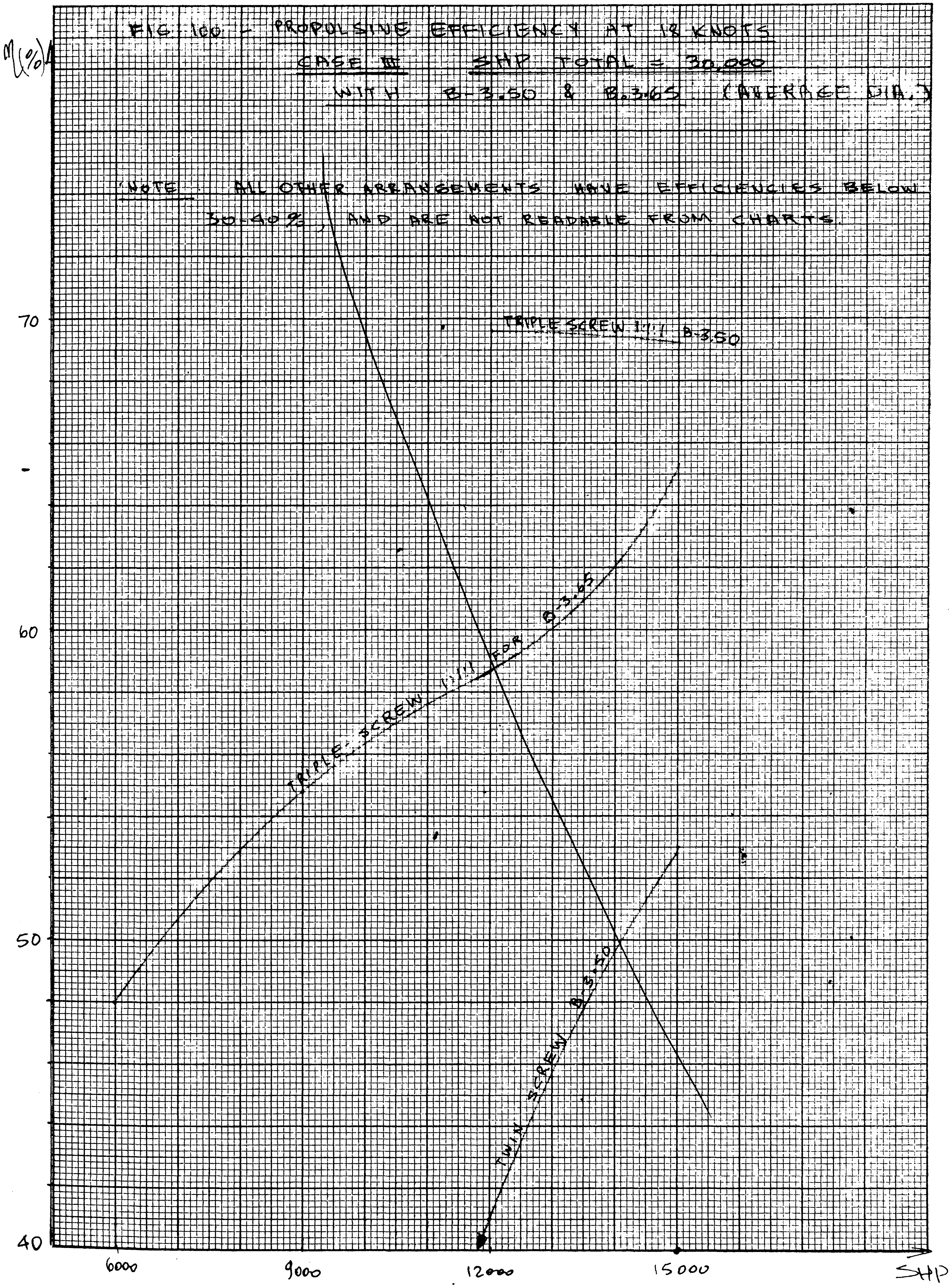


FIG. 100 - PROPULSIVE EFFICIENCY AT 18 KNOTS
CASE III SHP TOTAL = 30,000
WITH B-3.50 & B-3.65 (AVERAGE DIA.)
NOTE: ALL OTHER ARRANGEMENTS HAVE EFFICIENCIES BELOW 30-40%, AND ARE NOT READABLE FROM CHARTS.
η(%)
70
60
50
40
TRIPLE SCREW 1:1:1 B-3.50
TRIPLE SCREW 1:1:1 FOR B-3.65
TWIN SCREW B-3.50
6000
9000
12000
15000
SHP

OUT

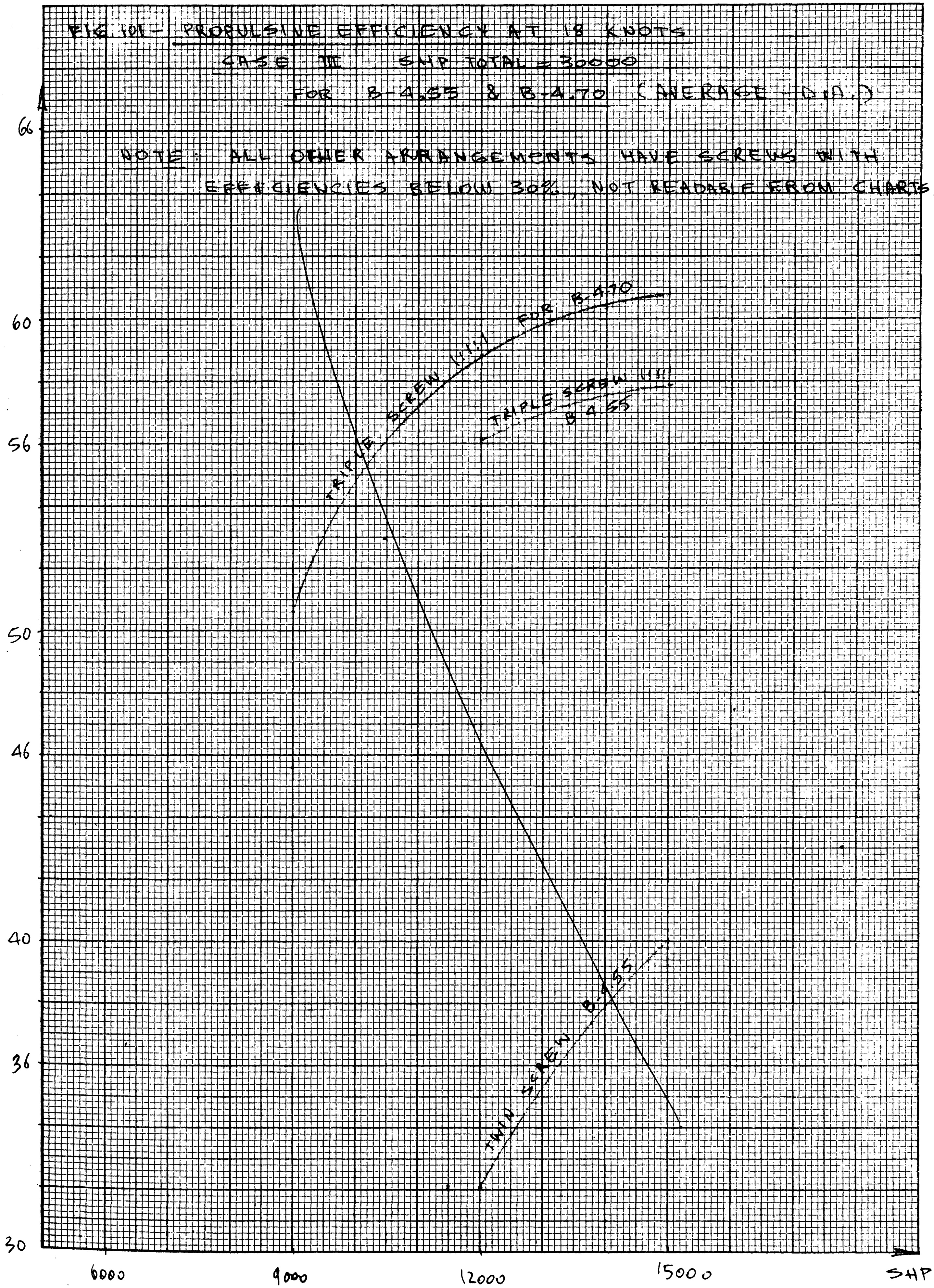


FIG 101 - PROPULSIVE EFFICIENCY AT 18 KNOTS
CASE III SHP TOTAL = 30000
FOR B-4.55 & B-4.70 (AVERAGE - D.A.)

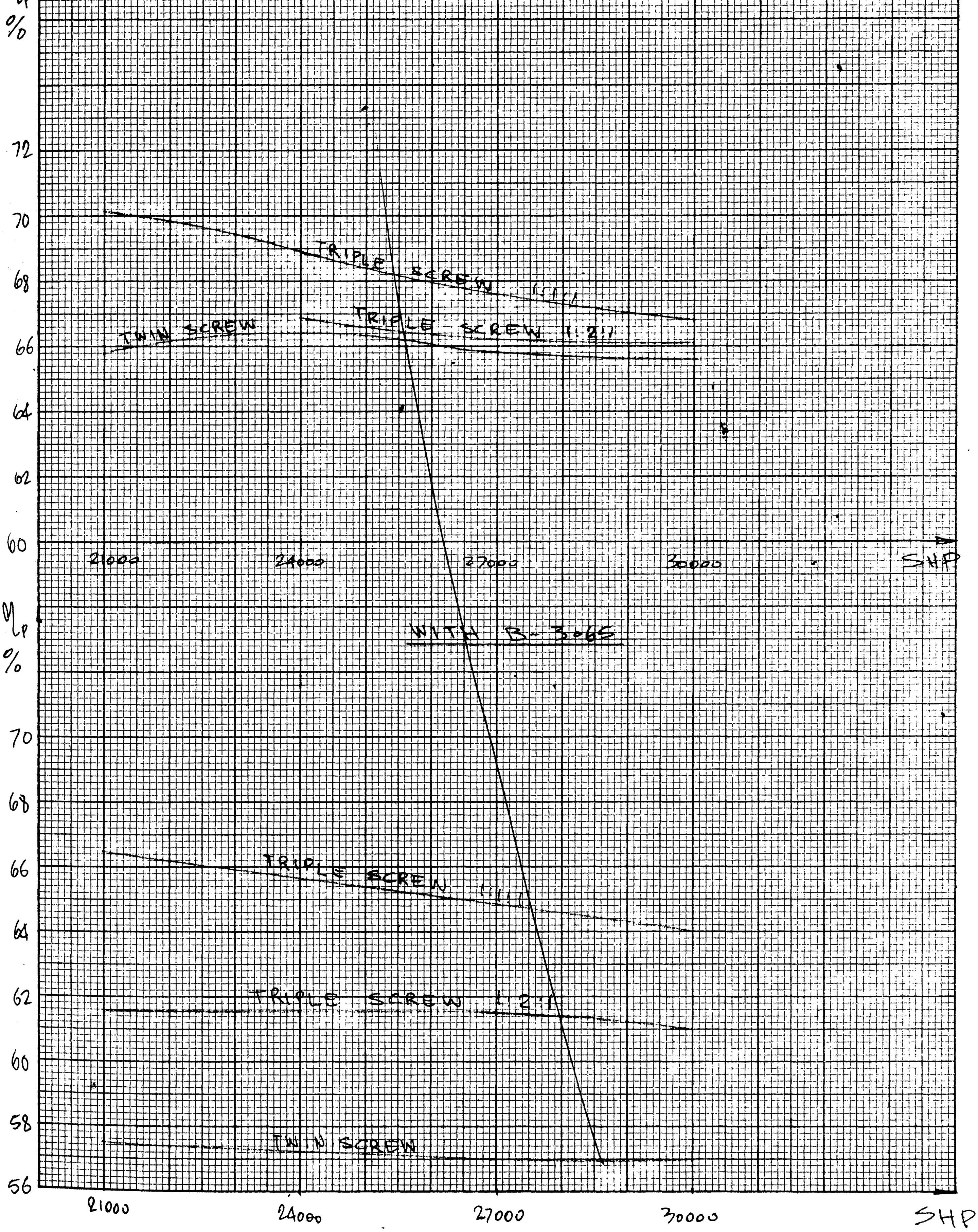
NOTE: ALL OTHER ARRANGEMENTS HAVE SCREWS WITH EFFICIENCIES BELOW 30%, NOT READABLE FROM CHARTS.

OUT.

FIG. 102 - PROPULSIVE EFFICIENCY AT 18 KNOTS

CASE III SHP TOTAL = 45000

WITH B-3-50 (AVERAGE DIA.)



OUT

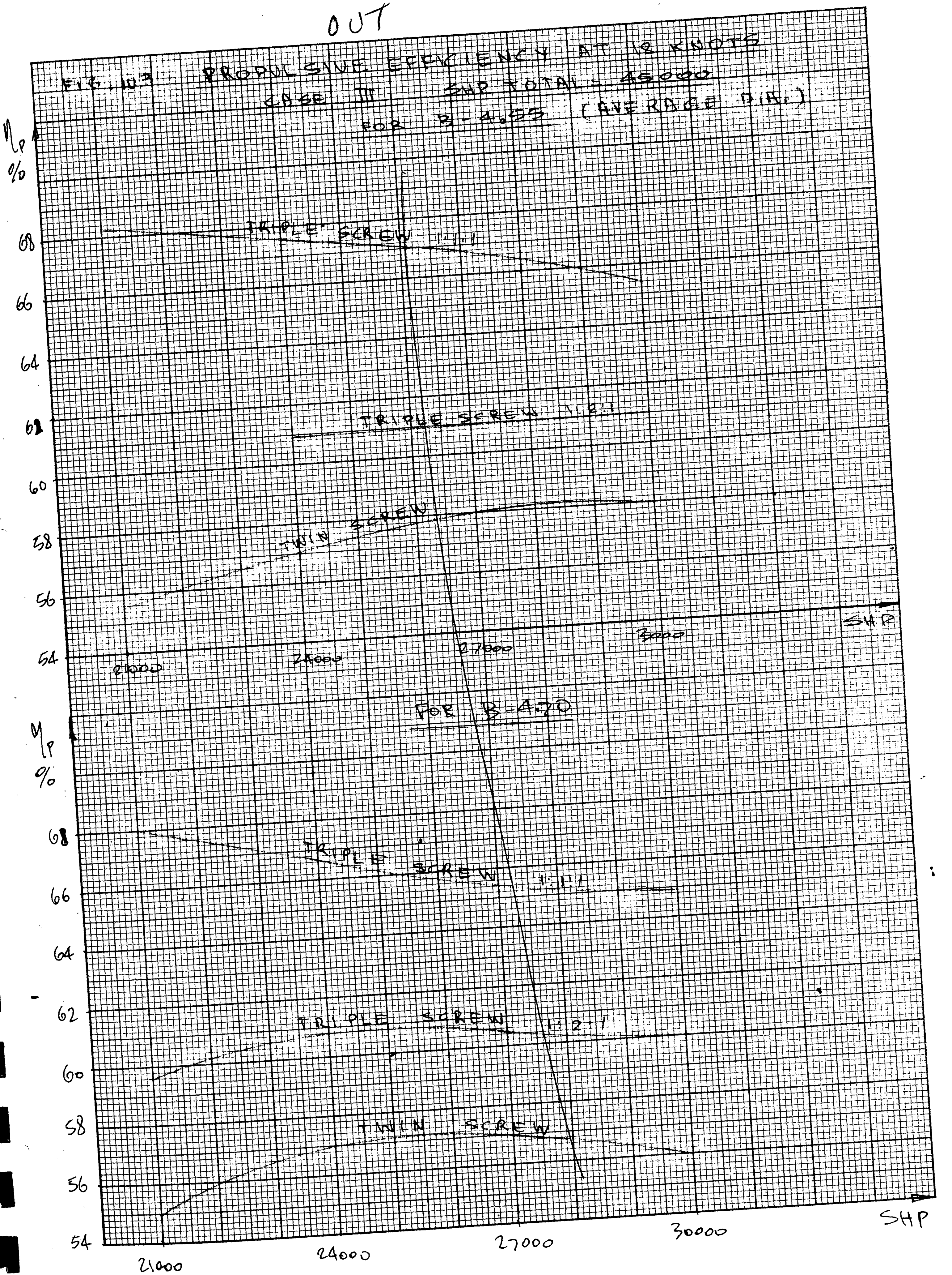


FIG. 103 PROPULSIVE EFFICIENCY AT 18 KNOTS
CASE III SHP TOTAL - 45000
FOR B-4.55 (AVERAGE DIA.)
η_p %
68
66
64
62
60
58
56
54
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:2:1
TWIN SCREW
SHP
2000
24000
27000
3000
FOR B-4.70
η_p %
68
66
64
62
60
58
56
54
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:2:1
TWIN SCREW
SHP
21000
24000
27000
30000

OUT

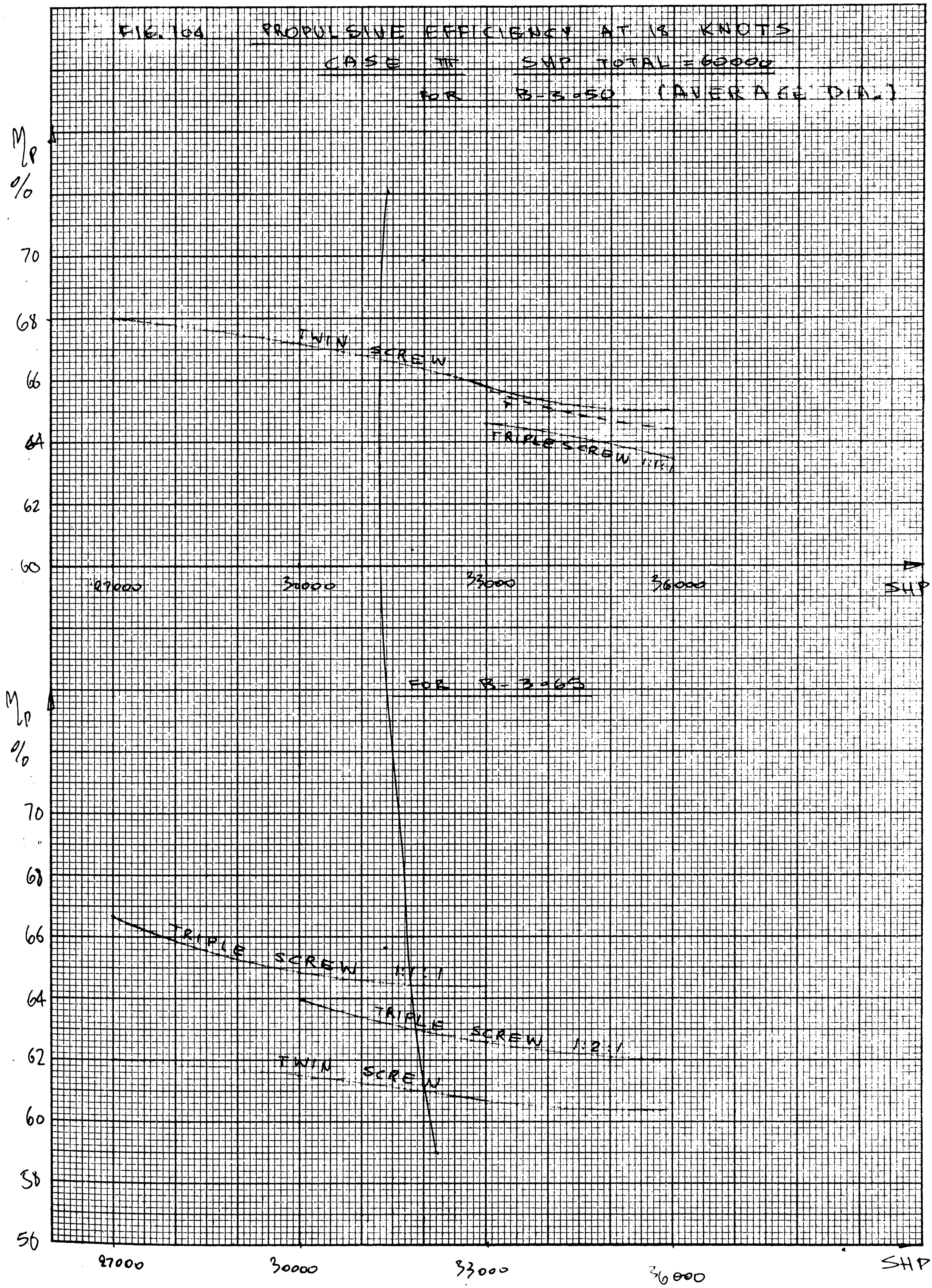


FIG. 164 PROPULSIVE EFFICIENCY AT 18 KNOTS
CASE III SHP TOTAL = 60000
FOR B-3-50 (AVERAGE DIA.)
ηp %
70
68
66
64
62
60
TWIN SCREW
TRIPLE SCREW 1:1:1
27000
30000
33000
36000
SHP
FOR B-3-65
ηp %
70
68
66
64
62
60
58
56
TRIPLE SCREW 1:1:1
TRIPLE SCREW 1:2:1
TWIN SCREW
27000
30000
33000
36000
SHP

OUT

FIG. 115 PROPULSIVE EFFICIENCY AT 18 KNOTS

CASE III SHP TOTAL = 60000

FOR B-4.55 (AVERAGE DIA.)