THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
DEPARTMENT OF NAVAL ARCHITECTURE AND MARINE ENGINEERING
SHIP HYDRODYNAMICS LABORATORY

Turning Characteristics of U. S. Coast Guard Icebreaker M-5

LT. J. D. PORRICELLI, USCG
Project Director: FINN C. MICHELSEN

Under contract with:

United States Coast Guard
Contract No. Tcg-17850-A
Washington, D. C.

Administered through:

June 1967

OFFICE OF RESEARCH ADMINISTRATION • ANN ARBOR

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NOMENCLATURE

B	-	beam
D	-	final diameter (see Fig. 2)
H	-	draft
L	-	length between perpendiculars
V_A	-	approach speed
V_T	-	turning speed
lcg	-	longitudinal center of gravity
Δ	-	displacement
∇	-	volume
Ψ	-	model's steady-state drift angle
δ	-	rudder angle

INTRODUCTION

The turning characteristics of the "Proposed Parent Hull Form M5 Polar Icebreaker" for the U.S. Coast Guard were determined utilizing a radio controlled, free-running model in the University of Michigan Maneuvering Basin. This particular design incorporated a flapped, single, centerline rudder with a triple screw arrangment (see Fig. 1) and appears to provide acceptable turning characteristics for an icebreaker.

DESCRIPTION OF MODEL AND TEST EQUIPMENT

The model was constructed of wood to a scale of 1 to 48 in compliance with U.S. Coast Guard drawings furnished to The University of Michigan Ship Hydrodynamics Laboratory. The scale ratio was chosen in consideration of the Maneuvering Basin's dimensions (100 feet by 60 feet by 6 feet), the speed at which the model operated, as well as the propeller and rudder sizes. The physical characteristics of the model are presented in Table 1.

The model was self contained and suited for radio control of rudder angle and propeller RPM. Control was continuously variable over the entire available ranges. All propulsive power was supplied by a set of storage batteries and a fractional horsepower direct current motor. Since the only mode of test operations anticipated was with all three shafts turning, a single motor drove an idler shaft assembly which in turn was mechanically connected to the three propeller shafts. Thus, all three shafts turned in their prescribed manner of rotation at the same speed.

The radio control system is a three channel time shared multiplex system employing pulse width and pulse position modulation. Each of the two channels which were utilized in this particular series of tests operated a continuous motion linear servo motor. This motor either turns the rudder through a rack and gear arrangement or rotates a potentiometer which varies the input signal to the propulsion motor control transistors. The same channel that controls the propeller RPM also is designed to activate a flip-flop propeller rotation reverser. The net result is that the operator has control of rudder angle, shaft RPM, and direction of shaft rotation.

Two channels of telemetric equipment were installed in the model for transmitting rudder angle and shaft RPM. Each of the two telemetric channels consists of a miniature, encapsulated combined sub-carrier oscillator and an FM battery powered transmitter. The corresponding receivers are solid state double discriminator FM types with extremely high AM rejection ahcieved by the double FM operation of the system.

The shaft RPM were recorded by a magnetic pickup which was set along a thirty-tooth gear mounted on the shaft. The output of the pickup was applied directly to one of the model borne transmitters. The shaft RPM receiver's output was then put to an electronic counter and shaft RPM were monitored and recorded continuously.

The rudder shaft was mechanically joined to a 50000 ohm continuous potentiometer which was set between a 12 volt reference voltage. As the rudder moved off the zero-volt, zero angle of attack position the varying plus or minus voltage (corresponding to starboard and port movement respectively) was sent to the telemetric transmitter and was read ashore with a calibrated (volts to degrees) VTVM. Simultaneous and continuous monitoring and recording of RPM and rudder angle was thus possible.

The model was also equipped with forward and after perpendicular lights to facilitate the photographing of the free running model with a 16mm movie camera equipped with a 25mm lens and operating at 16 frames per second.

The Maneuvering Basin itself was covered with a grid system consisting of thirty constant tension lines and at intervals of 5 feet in both the x and y directions. A sufficient number of the grid intersections were marked so that at all times a reference point was present in the camera's field of vision. The model operated beneath the grid and in order to minimize the parallex error the aforementioned forward and after perpendicular lights were raised on masts such that they stood just below the grid. Thus, in essense the camera was tracking two points in a plane.

TEST PROGRAM AND DATA

The test program basically consisted of evaluating the model's turning characteristics over the prototype's proposed speed range. The four speeds that complete data was recorded were 4.5 kts, 8.75 kts, 10.0 kts, and 15.0 kts.

At each of these speeds both port and starboard turns were made over a range of rudder angles. The upper limit of these rudder angles was dictated by the physical limits of the continuous motion linear servo motor and the lower limit of these angles was governed by the dimensions of the Maneuvering Basin itself. These limits allowed rudder angles of 40, 35, 30, 25, and 20 degrees both to port and starboard.

In all cases, all three screws were turning the same speed in their prescribed manner of rotation.

For each run, the model was timed on its approach course to verify its approach speed. When the rudder was put over to some prescribed angle the movie camera began to track the two mast lights below the grid. Simultaneously, a continuous recording and monitoring of shaft RPM was kept. Essentially, constant shaft RPM were maintained throughout each turn as noted in Table 2 with no more than $\pm$ 2 RPM.

When the vessel reached its steady turn, the time to complete the 360 degree was taken and knowing the circle circumference, the turning speed was acquired.

A visual plot of the two mast lights was also maintaned throughout each turn. This was easily accomplished due to the grid over the tank, the intersection markers, and the actual speed of the model. This was intended primarily as a "quick-check" plot and as a guide when the subsequent acquisition of data from the movie films was accomplished. However, it was found that two men tracking the lights (one the forward light, the other the after light) with some practice could compile a coordinated plot whose results were extremely good when compared to the data acquired from the film.

The film, upon developing, was run through a previewer and viewed at stipulated frame intervals. Knowing the film speed, a continous time-location plot was constructed for each run of the lcg of the vessel utilizing the photographed grid. Also taken off the film was the drift angle for each of the times noted and the initiation of rudder application. These plots were matched with the recorded RPM and rudder angle and are tabulated in Table 2 and graphically displayed in Figures 3-42.

DISCUSSION

The greatly increased attention that has been recently devoted to the maneuverability of ships has drawn to light the difficulties involved in the experimental study of the problem using small scale, free running models of the prototype. In particular, the use of 6 to 10 foot models provides the appropriate size for use in the University of Michigan Maneuvering Basin. However, as with any model a shortcoming in the scaling will be magnified more so as the model becomes smaller.

This is especially the case with a self propelled model where the propeller diameters are less than 6 to 7 inches and the rudders are correspondingly small. In fact, when these components are of this magnitude, one is never entirely sure what, if any, scaling law applies. The introduction of the "non-scaling" rudder and propellers which are not present with restrained model tests yield complications that question the reliability of the data obtained.

Thus, it is desirable to utilize the largest model possible and then determine if the scale chosen is such that the Froude scaling of the model results in the true maneuvering characteristics of the prototype. Within the scope of the tests conducted at this facility, no definitive scale effects could be found which were directly attributable to the model itself or its self propulsive features.

The turning characteristics of this hull form for any given rudder angle (see Table 2 and Figures 3 through 42 and Figures 44 and 45) remain constant over the speed range until the vessel exceeds a speed-length ratio of approximately 0.65 at which point the turning diameters begin to slowly increase. There is one exception to this which occurs during low speed, starboard turns where the turning diameter versus speed curve experiences an increase in diameter at the low end of the speed scale. The only explanation for this effect is due to:

1. the Hovgaard effect at low ship speeds which for this propeller arrangment would tend to force the stern to starboard;
2. the unbalanced wake created by the right hand turning centerline propeller which would induce a tendency to turn the vessel to port; and,
3. the sense of rotation of the centerline propeller which creates a force in such a direction as to push the stern to starboard.

All of these effects at low speeds where the lift created by the rudder is small, oppose the turn to starboard and thus explain the observed worsening of the turning characteristics.

It is also seen on these same figures that the vessel in all cases (with the above mentioned exception) turns in a tighter circle to starboard than to port for any corresponding speed and rudder angle. The drift angle, on the other hand, was always greater in a port turn than in a similar starboard turn. Both of these characteristics are more or less in compliance with conventional right hand turning single screw vessels and in accordance with a simple force analysis on the propellers and pressure differential analysis on the single centerline rudder.

An analysis was made on approach speed versus steady state turning speed (see Table 2 and Fig. 46). Here it is seen that the vessel has a slower turning speed to starboard than to port for any given approach speed and rudder angle. Also, the higher the angle of attack imposed on the rudder, the slower was the turning speed for a given approach speed as would be expected. Finally, the turn speed-approach speed ratio varied from approximately 0.6 to 0.8 as a general rule and was dependent solely on the two parameters, approach speed and rudder angle.

TABLE 1

Particulars of Model 1018 - USCG Icebreaker M5

λ	48	
LOA	8.375	Ft.
LWL or L	7.667	Ft.
H	0.625	Ft.
B	1.667	Ft.
Δ	282.4	Lbs.
∇	4.526	Cu. Ft.
Rudder rate	3.03	Deg/Sec
Number of propellers	3	
Propeller diameter	4.25	In.
Pitch-diameter ratio	0.85	
Type of propeller	Troost B4.55	
Propeller Rotation	Port - LH Center - RH Starboard - RH	

TABLE 2

Turning Characteristics

V_A (Kts)	δ (Degrees)	V_T (Kts)	Ψ (Degrees)	D (Ft)	$V_A/\overline{V_L}$	D/L
15	40S	9.15	12.25	1525	0.782	4.12
	35S	9.90	11.00	1605		4.34
	30S	11.02	10.50	1695		4.58
	25S	11.65	10.25	1815		4.90
	20S	12.30	10.00	1995		5.39
	40P	9.70	11.50	1775		4.80
	35P	10.60	10.75	1895		5.12
	30P	11.47	10.50	2040		5.52
	25P	12.18	9.50	2265		6.12
	20P	12.96	9.00	2560		6.92
10	40S	6.24	12.00	1518	0.521	4.10
	35S	6.83	10.50	1590		4.30
	30S	7.59	10.00	1685		4.55
	25S	8.05	9.25	1805		4.88
	20S	8.62	9.00	1980		5.35
	40P	6.85	12.50	1758		4.75
	35P	7.49	12.25	1875		5.07
	30P	7.96	11.25	2020		5.46
	25P	8.45	10.50	2242		6.06
	20P	9.07	10.00	2540		6.86
8.75	40S	5.48	10.75	1518	0.460	4.10
	35S	5.95	10.25	1595		4.31
	30S	6.69	9.25	1690		4.56
	25S	7.06	9.00	1815		4.90
	20S	7.57	8.50	1985		5.36
	40P	6.04	12.50	1758		4.75
	35P	6.48	12.25	1870		5.05
	30P	6.95	11.25	2015		5.45
	25P	7.46	10.75	2235		6.05
	20P	7.98	10.50	2535		6.85
4.5	40S	2.79	11.25	1665	0.229	4.50
	35S	3.37	11.00	1765		4.77
	30S	3.59	10.75	1885		5.10
	25S	3.62	9.50	2060		5.56
	20S	4.15	9.25	2230		6.02
	40P	3.30	11.50	1758		4.75
	35P	3.55	11.00	1870		5.06
	30P	3.69	10.50	2020		5.46
	25P	4.02	10.25	2235		6.05
	20P	4.40	9.75	2535		6.85

PROFILE VIEW OF STERN SECTION USCG ICEBREAKER
MODEL M5

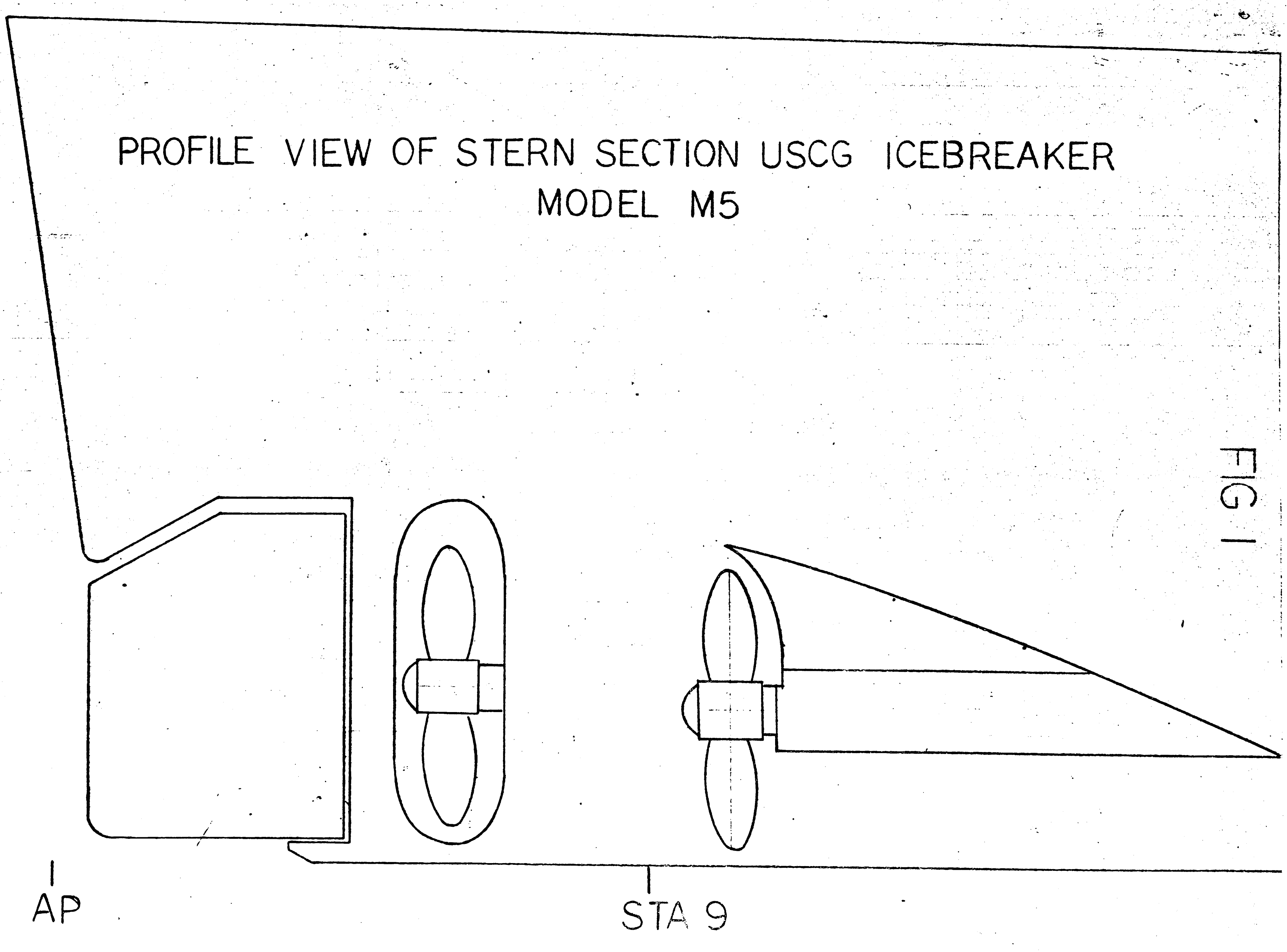
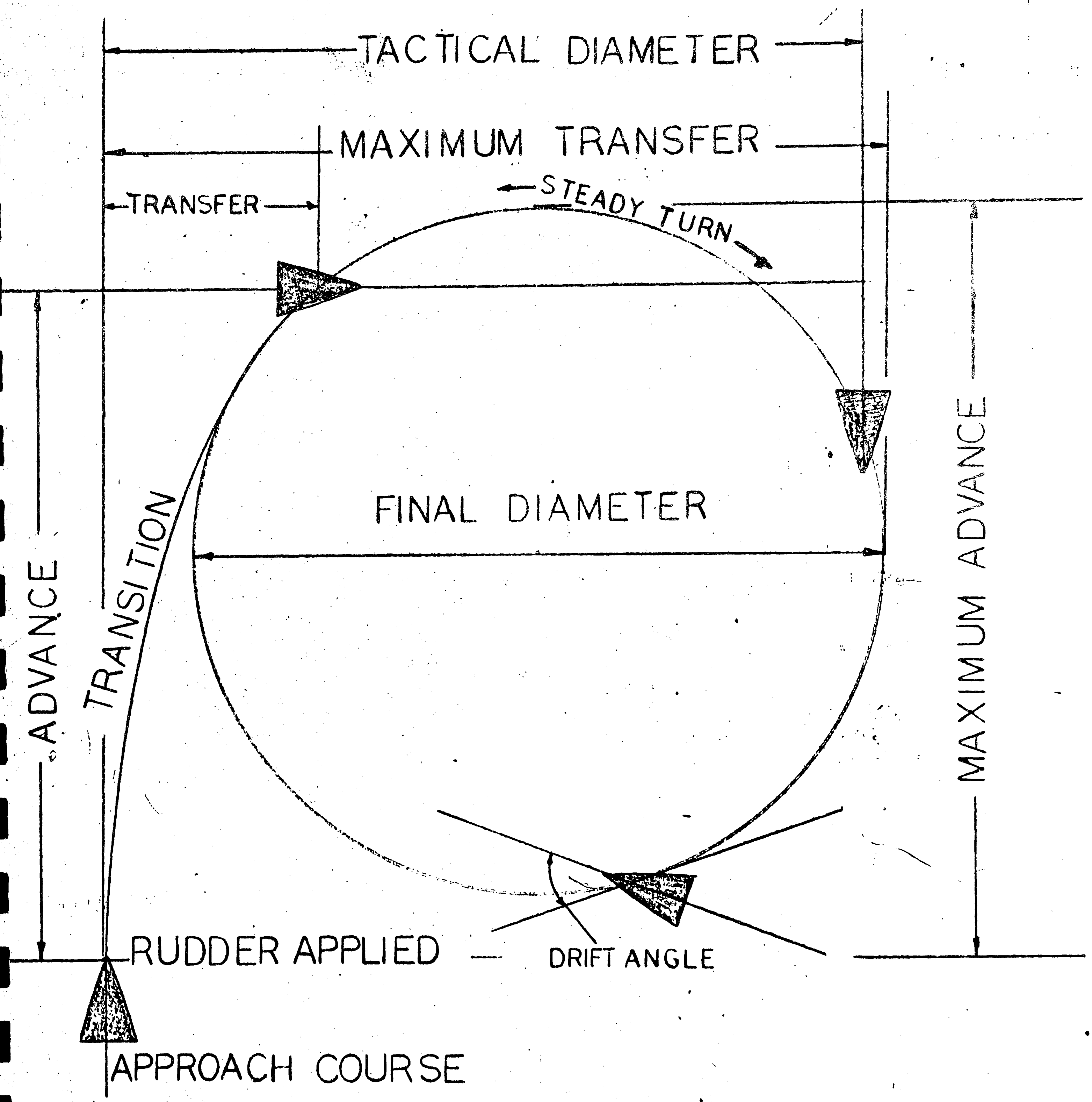


FIG 1

SCALE 1/8" = 1'

FIG 2

DEFINITION OF TURNING MANEUVER



NOTE

On following diagrams, the vectors representing the model are drawn with a drift angle equal to twice their actual angular values in order to present a clearer graphical display. All other values are drawn with a scale of 1" equaling 480'.

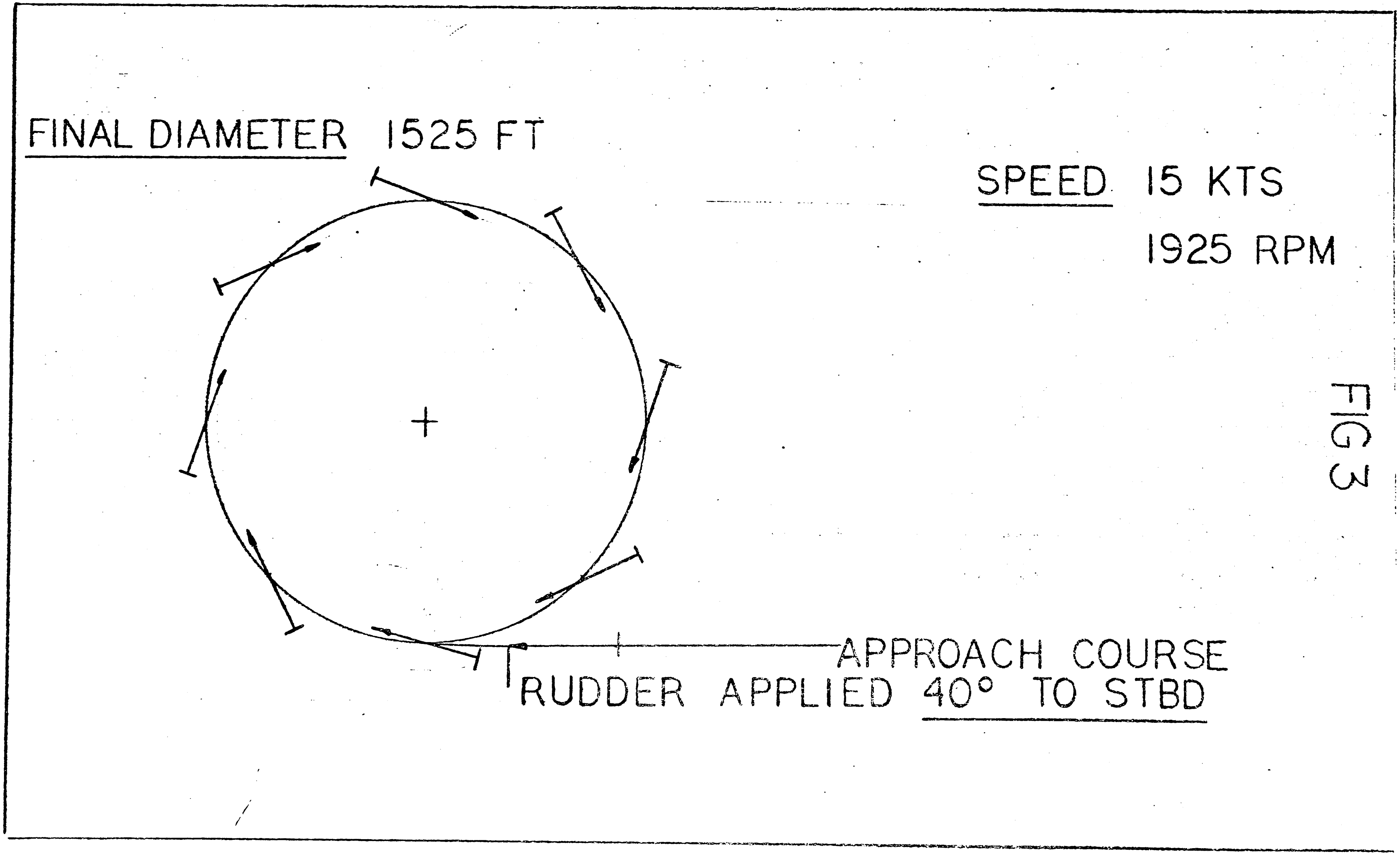

FINAL DIAMETER 1525 FT
SPEED 15 KTS
1925 RPM
APPROACH COURSE
RUDDER APPLIED 40° TO STBD

FIG 3

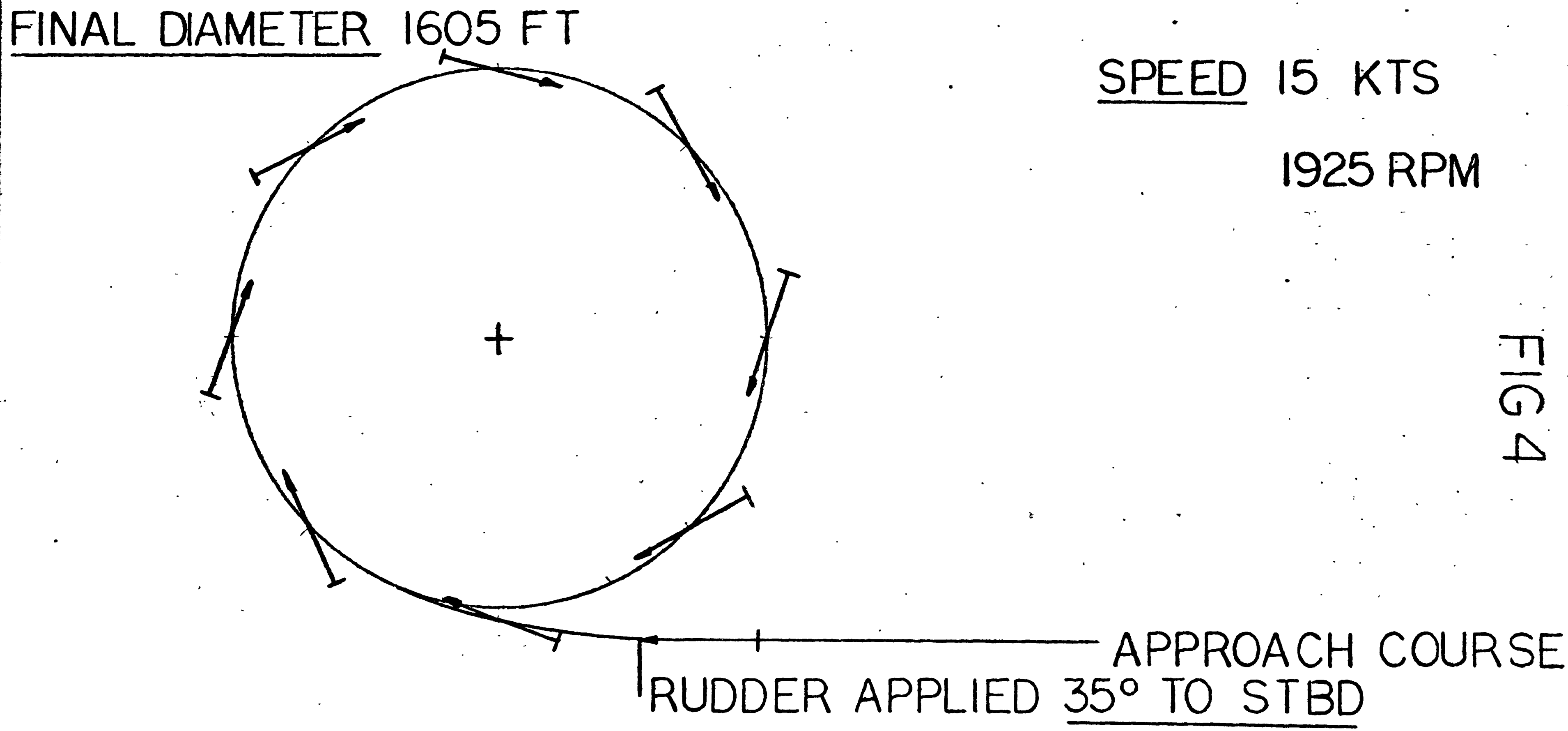

FINAL DIAMETER 1605 FT
SPEED 15 KTS
1925 RPM
APPROACH COURSE
RUDDER APPLIED 35° TO STBD

FIG 4

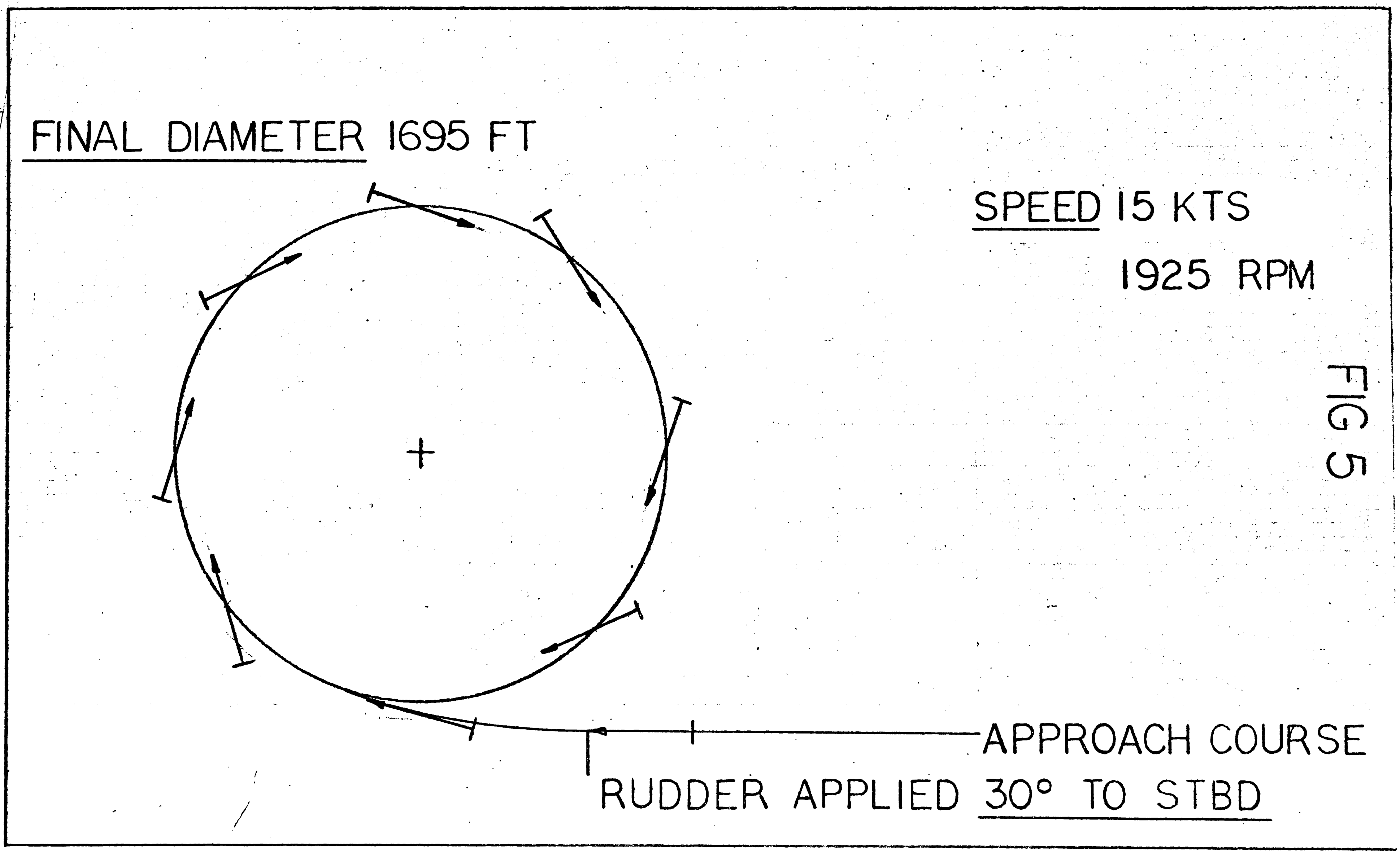

FINAL DIAMETER 1695 FT
SPEED 15 KTS
1925 RPM
APPROACH COURSE
RUDDER APPLIED 30° TO STBD

FIG 5

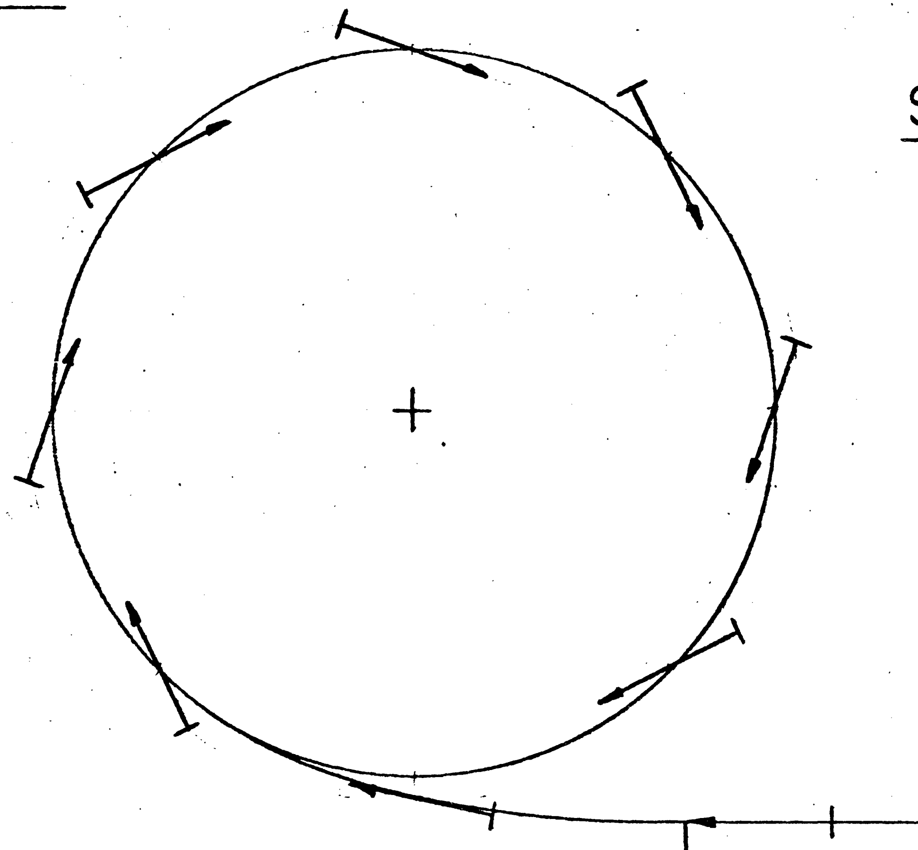
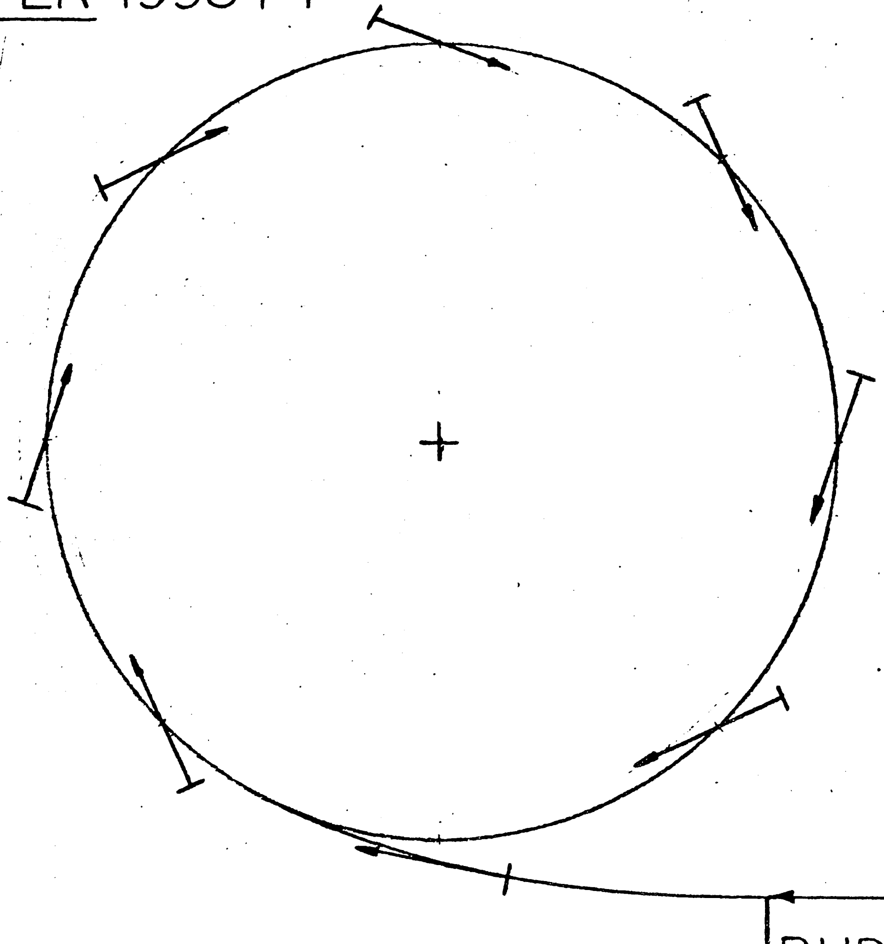

FINAL DIAMETER 1815 FT
SPEED 15 KTS
1925 RPM
APPROACH COURSE
RUDDER APPLIED 25° TO STB[

FIG 6



FINAL DIAMETER 1995 FT
SPEED 15 KTS
1925 RPM
APPROACH COURSE
RUDDER APPLIED 20° TO STBD

FIG 7

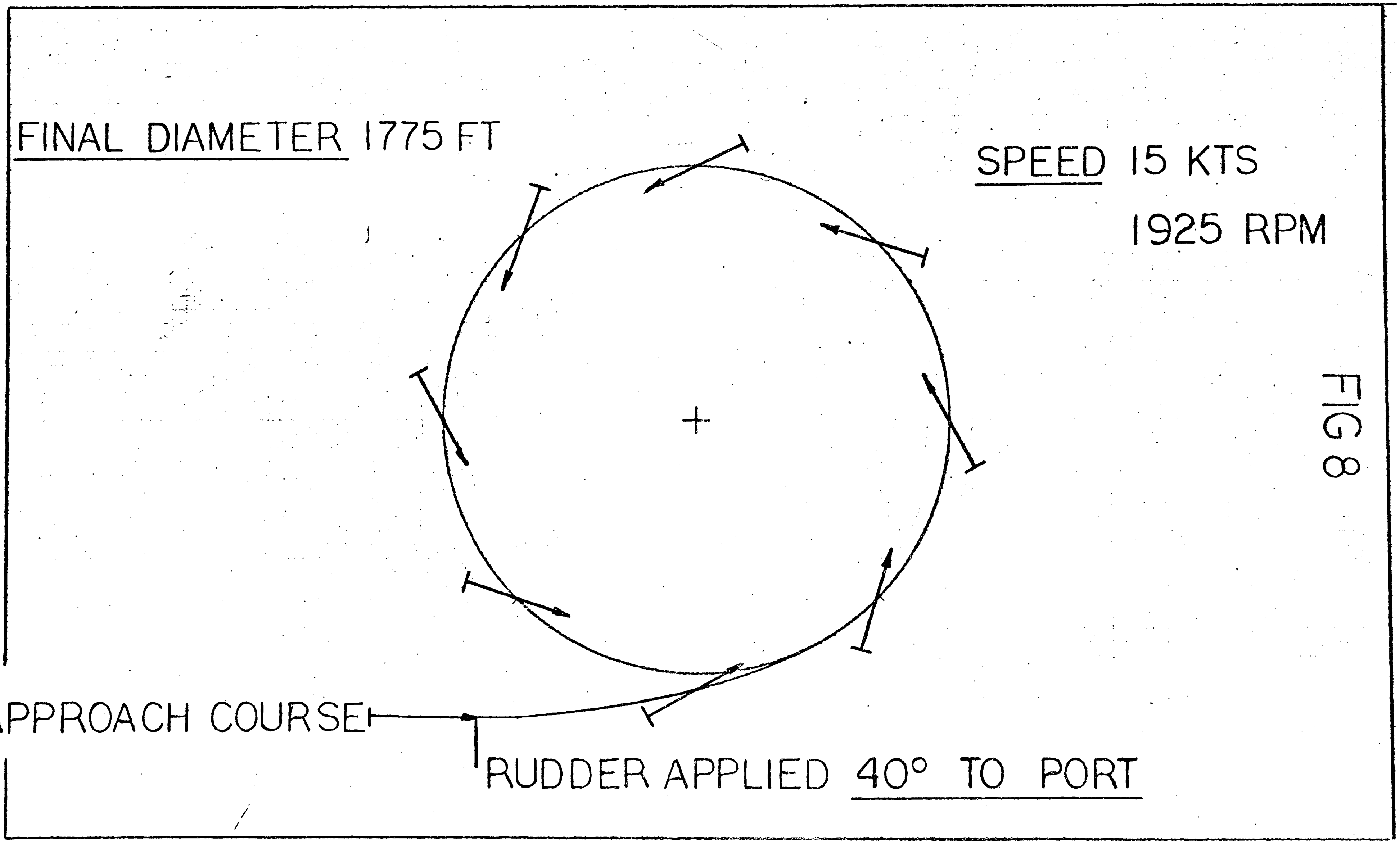

FINAL DIAMETER 1775 FT
SPEED 15 KTS
1925 RPM
APPROACH COURSE
RUDDER APPLIED 40° TO PORT

FIG 8

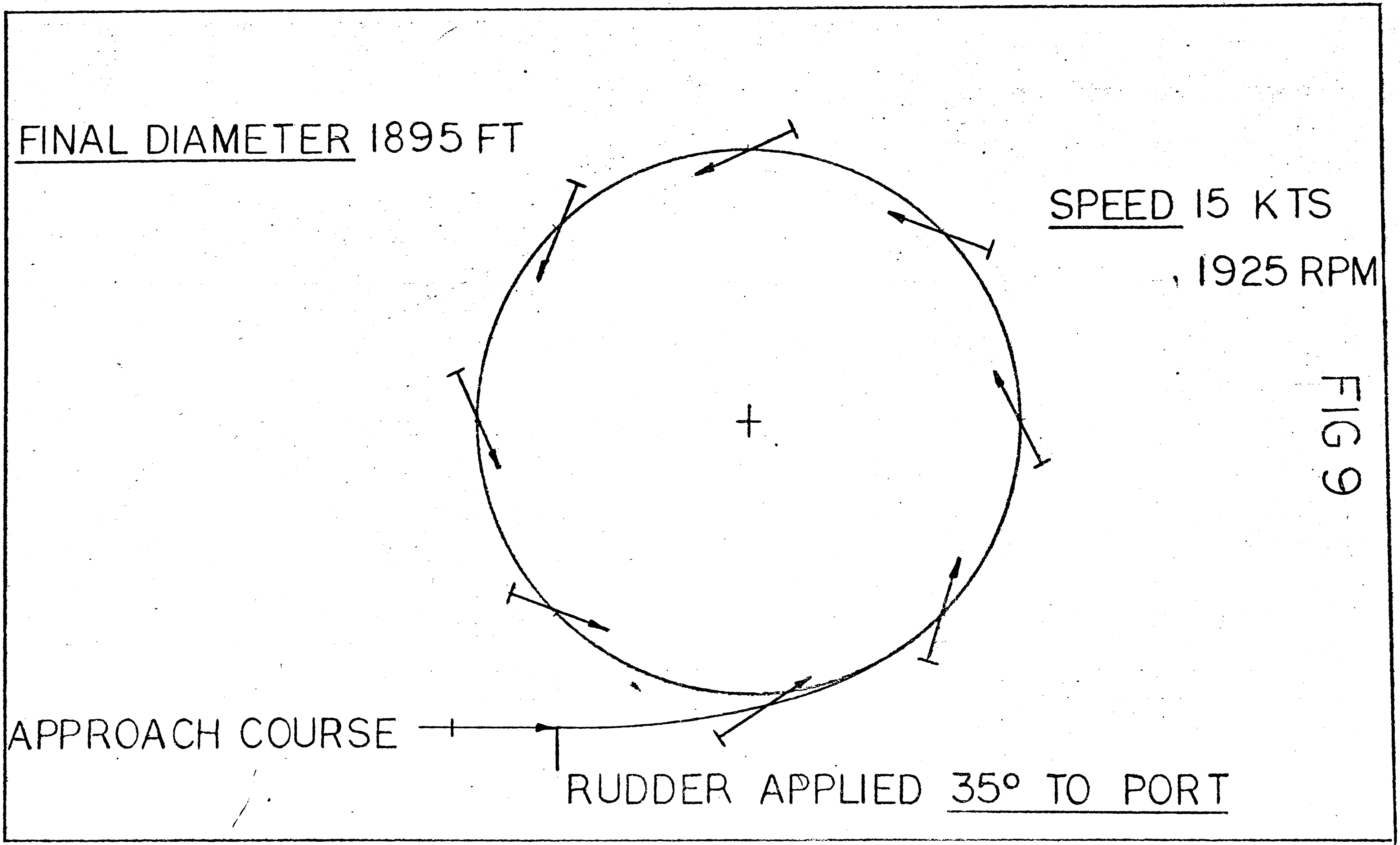

FINAL DIAMETER 1895 FT
SPEED 15 KTS
, 1925 RPM
APPROACH COURSE
RUDDER APPLIED 35° TO PORT

FIG 9

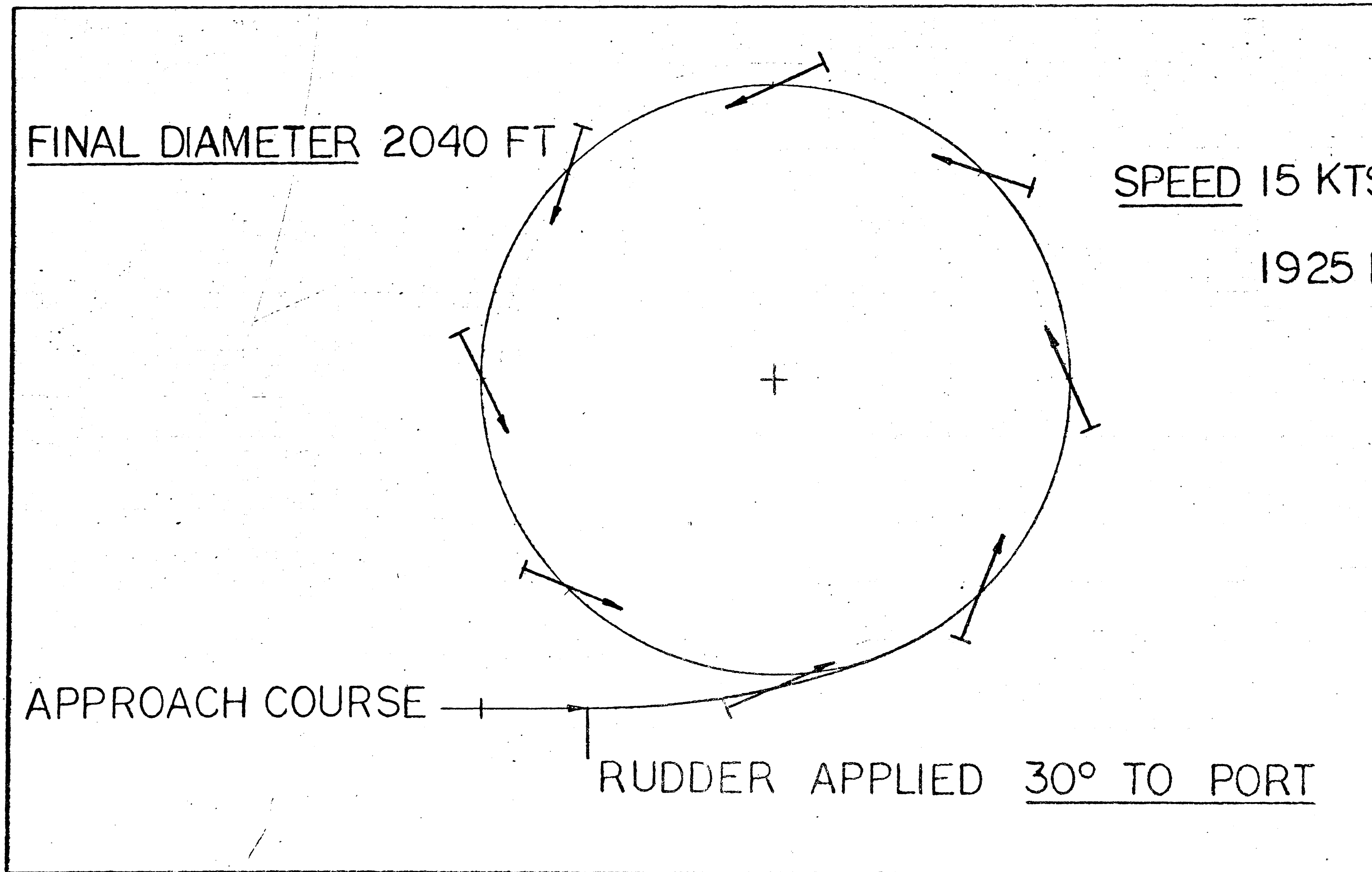

FINAL DIAMETER 2040 FT
SPEED 15 KTS
1925 RPM
APPROACH COURSE
RUDDER APPLIED 30° TO PORT

FIG 10

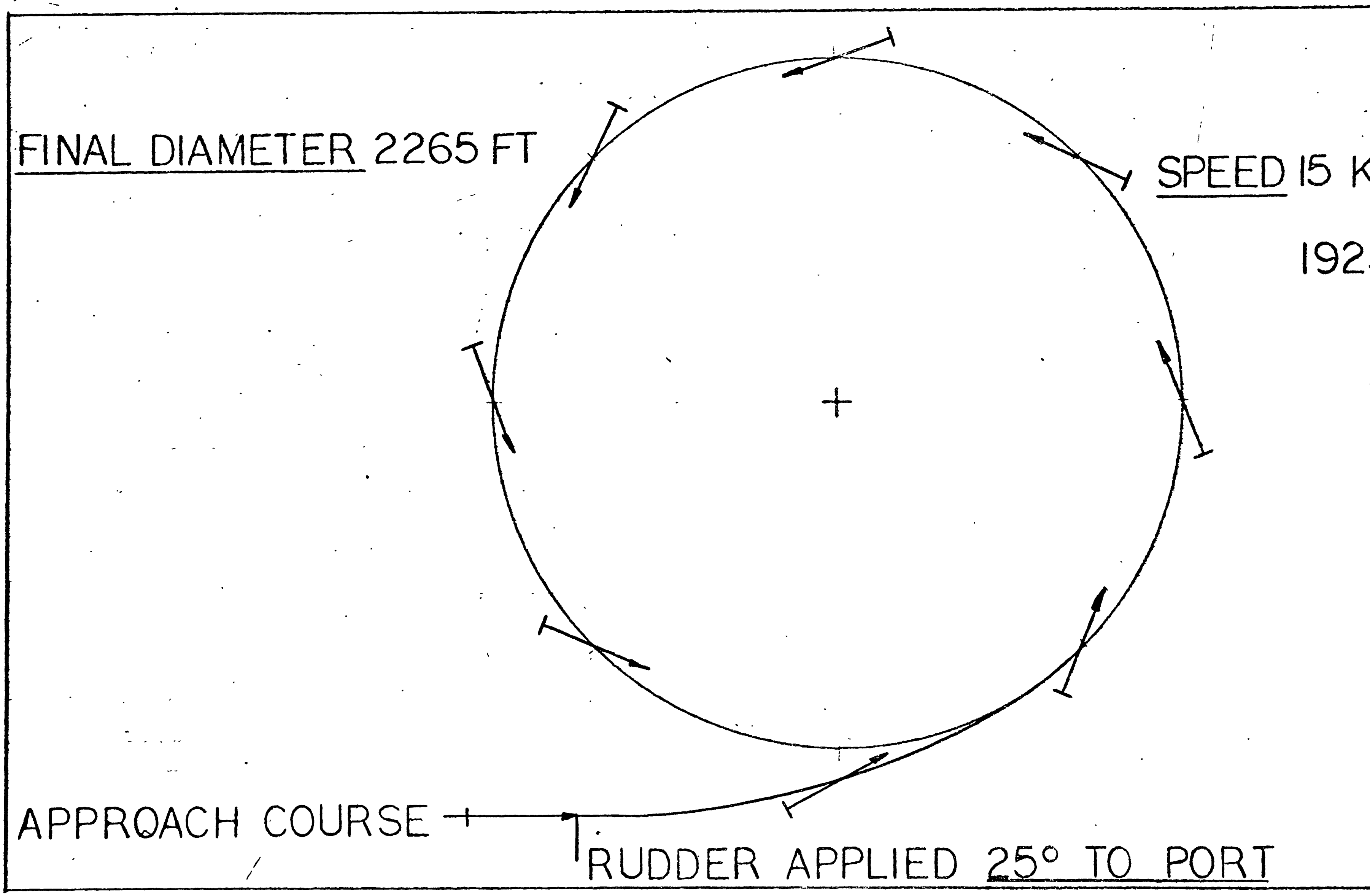

FINAL DIAMETER 2265 FT
SPEED 15 KTS
1925 RPM
APPROACH COURSE
RUDDER APPLIED 25° TO PORT

FIG 11

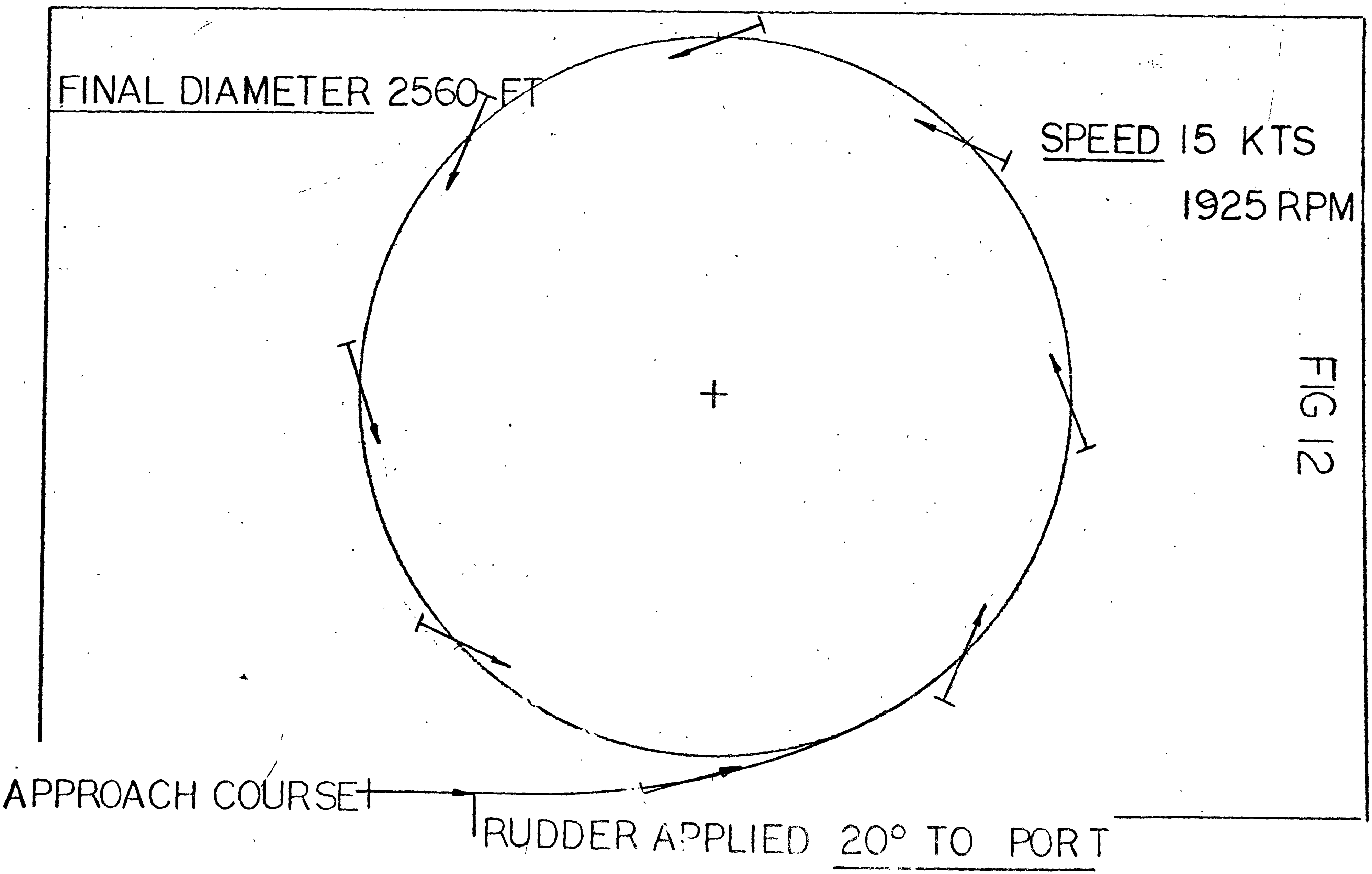

FINAL DIAMETER 2560 FT
SPEED 15 KTS
1925 RPM
APPROACH COURSE
RUDDER APPLIED 20° TO PORT

FIG 12

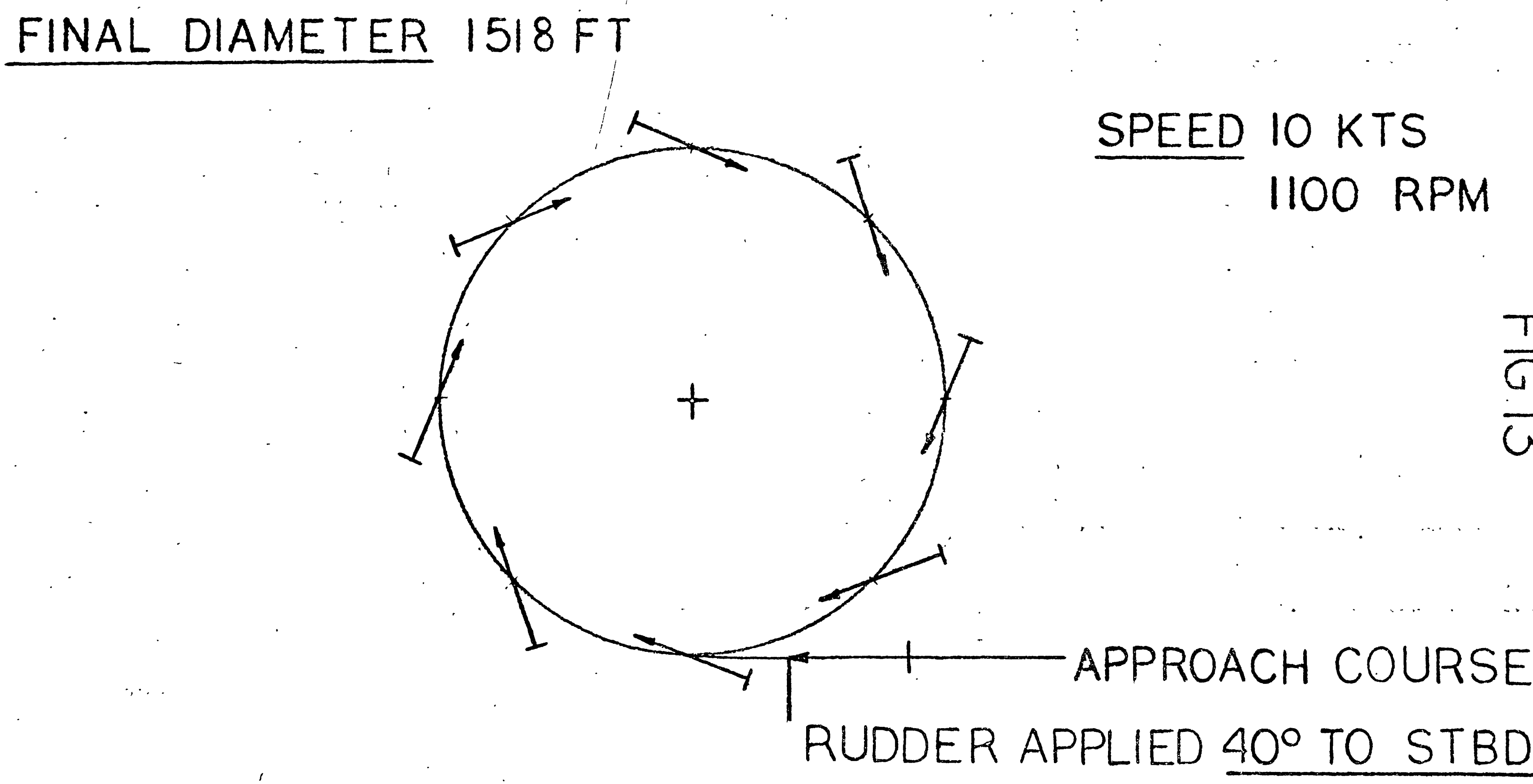

FINAL DIAMETER 1518 FT
SPEED 10 KTS
1100 RPM
APPROACH COURSE
RUDDER APPLIED 40° TO STBD

FIG 13

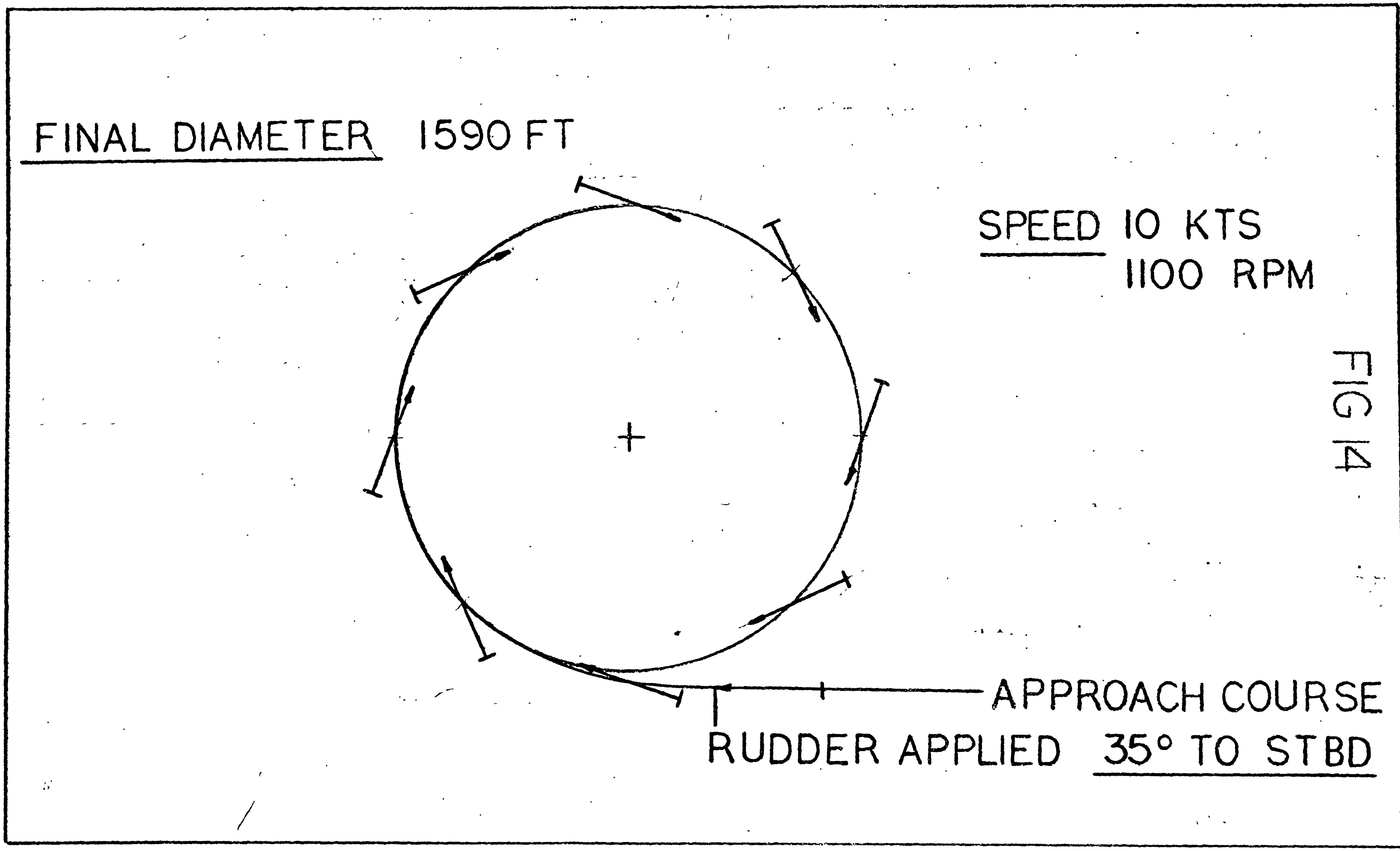

FINAL DIAMETER 1590 FT
SPEED 10 KTS
1100 RPM
APPROACH COURSE
RUDDER APPLIED 35° TO STBD

FIG 14

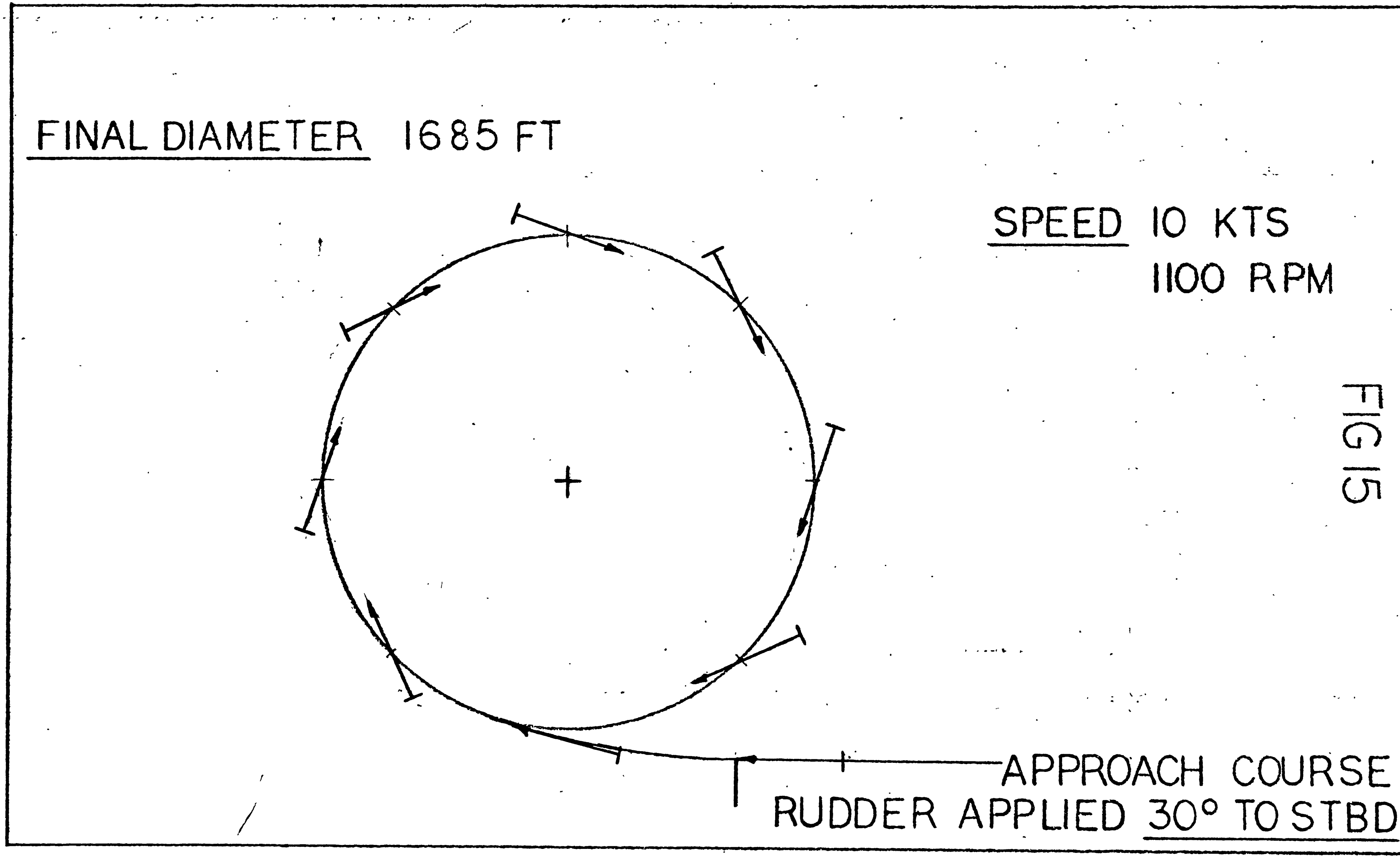

FINAL DIAMETER 1685 FT
SPEED 10 KTS
1100 RPM
APPROACH COURSE
RUDDER APPLIED 30° TO STBD

FIG 15

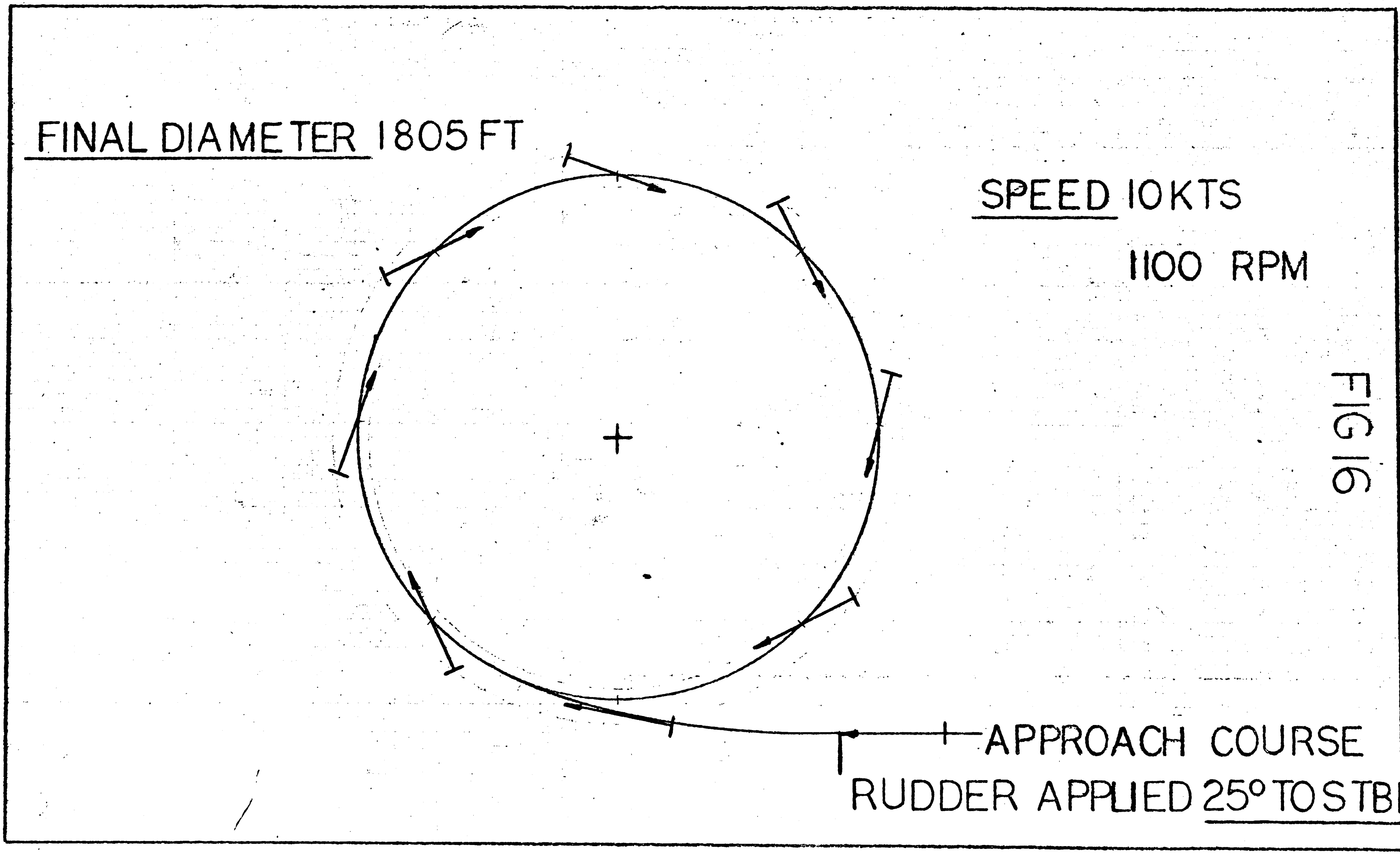

FINAL DIAMETER 1805 FT
SPEED 10 KTS
1100 RPM
APPROACH COURSE
RUDDER APPLIED 25° TO STBD

FIG 16

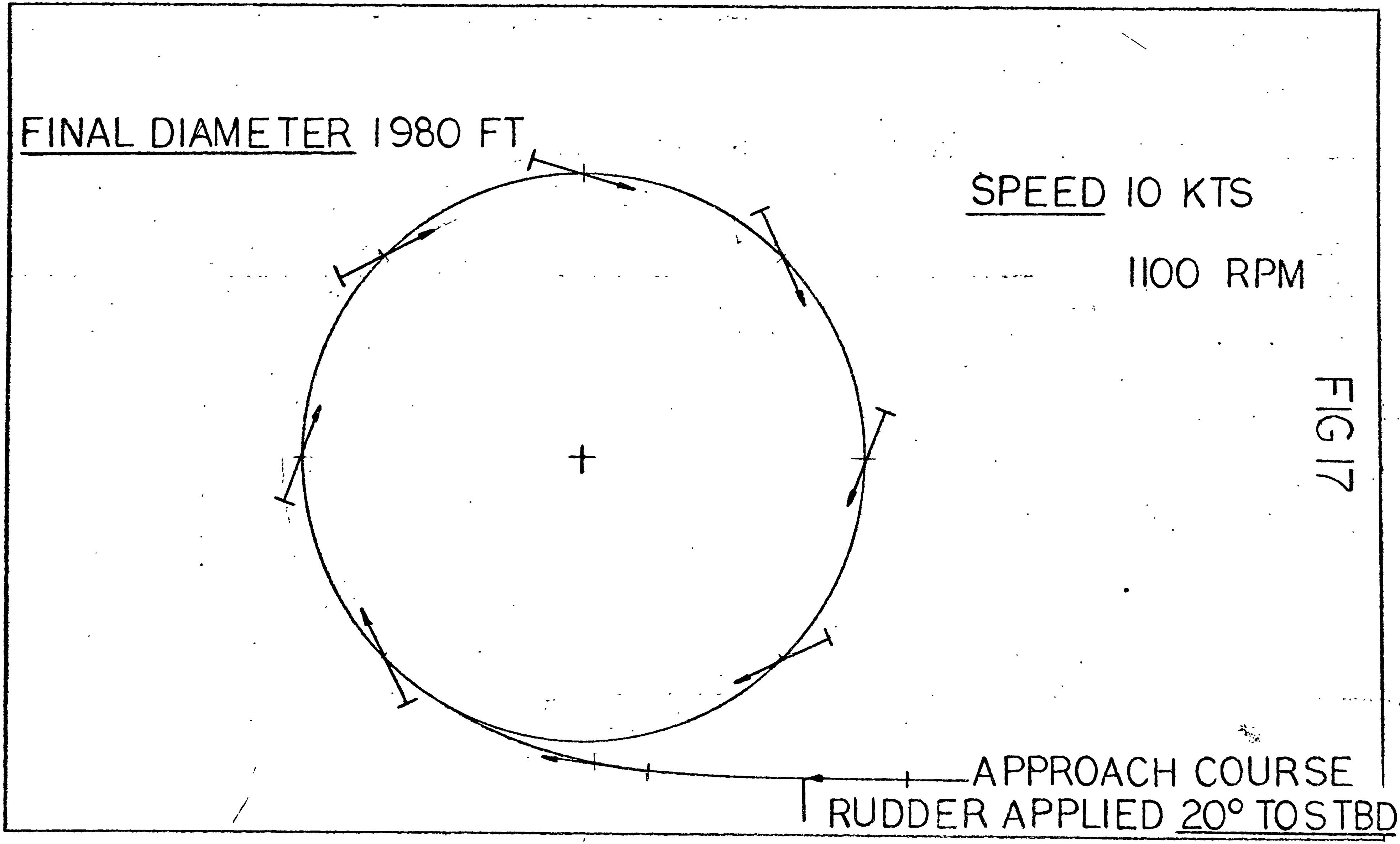

FINAL DIAMETER 1980 FT
SPEED 10 KTS
1100 RPM
APPROACH COURSE
RUDDER APPLIED 20° TO STBD

FIG 17

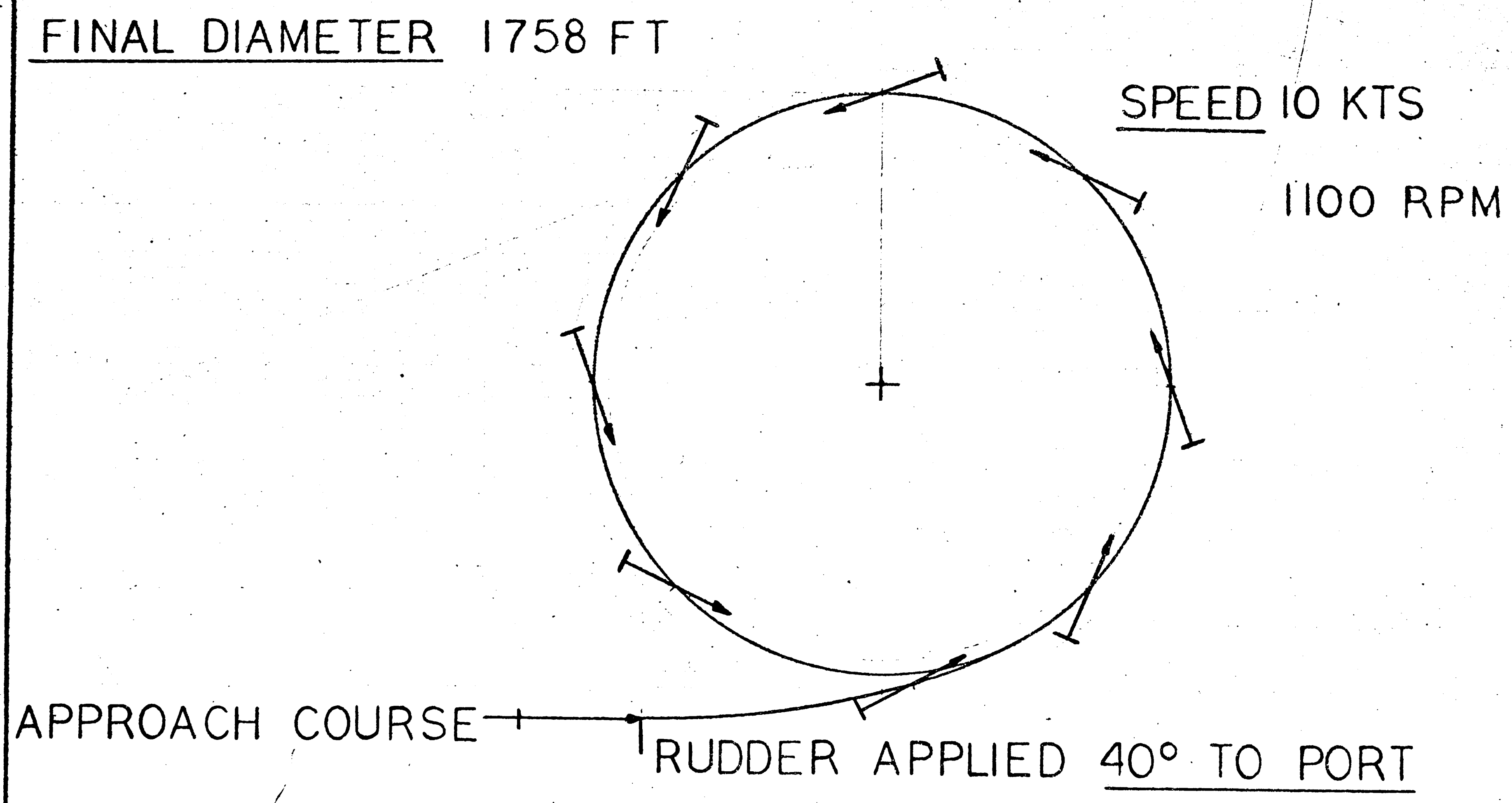

FINAL DIAMETER 1758 FT
SPEED 10 KTS
1100 RPM
APPROACH COURSE
RUDDER APPLIED 40° TO PORT

FIG 18

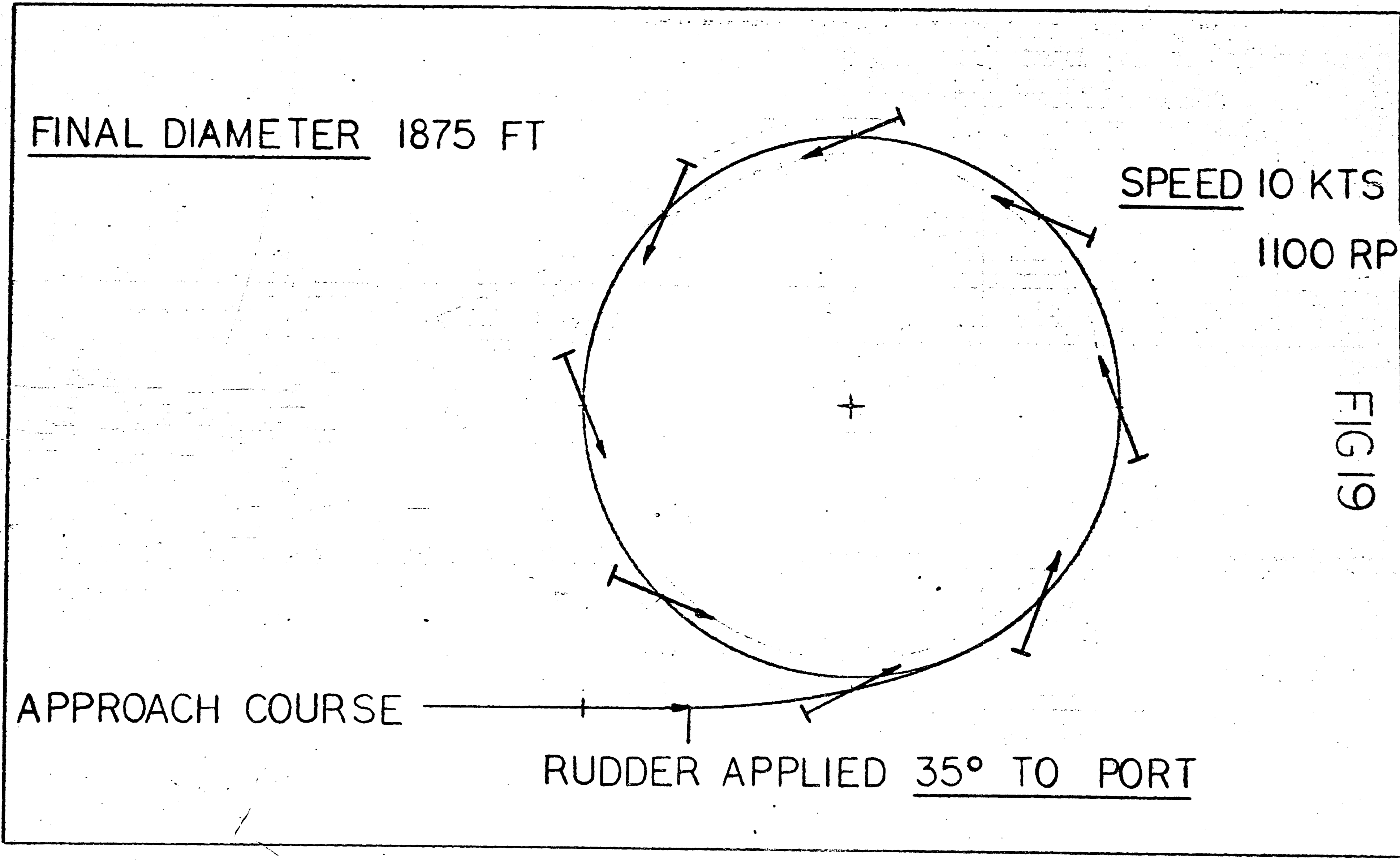

FINAL DIAMETER 1875 FT
SPEED 10 KTS
1100 RPM
APPROACH COURSE
RUDDER APPLIED 35° TO PORT

FIG 19

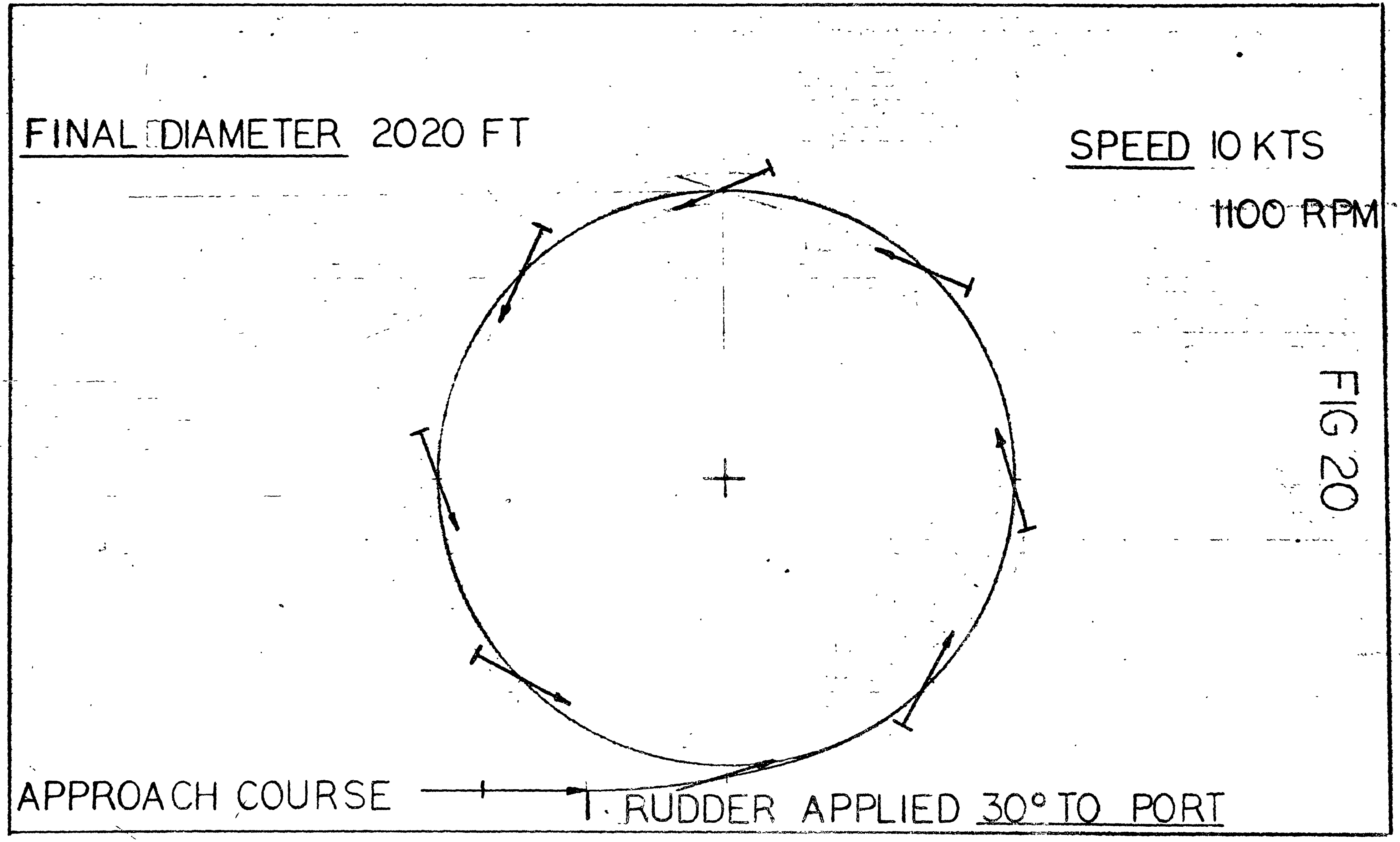

FINAL DIAMETER 2020 FT
SPEED 10 KTS
1100 RPM
APPROACH COURSE
RUDDER APPLIED 30° TO PORT

FIG 20

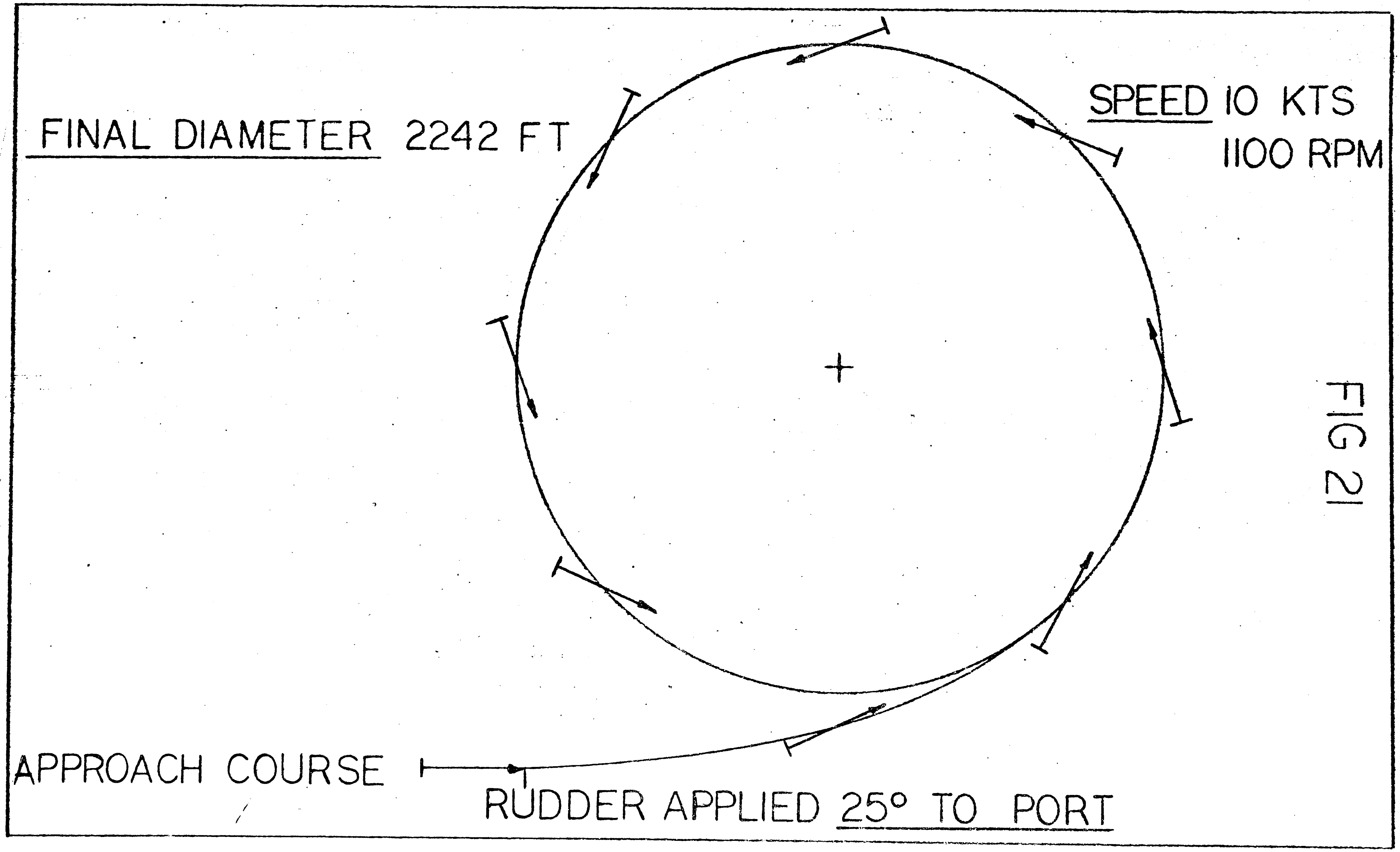

FINAL DIAMETER 2242 FT
SPEED 10 KTS
1100 RPM
APPROACH COURSE
RUDDER APPLIED 25° TO PORT

FIG 21

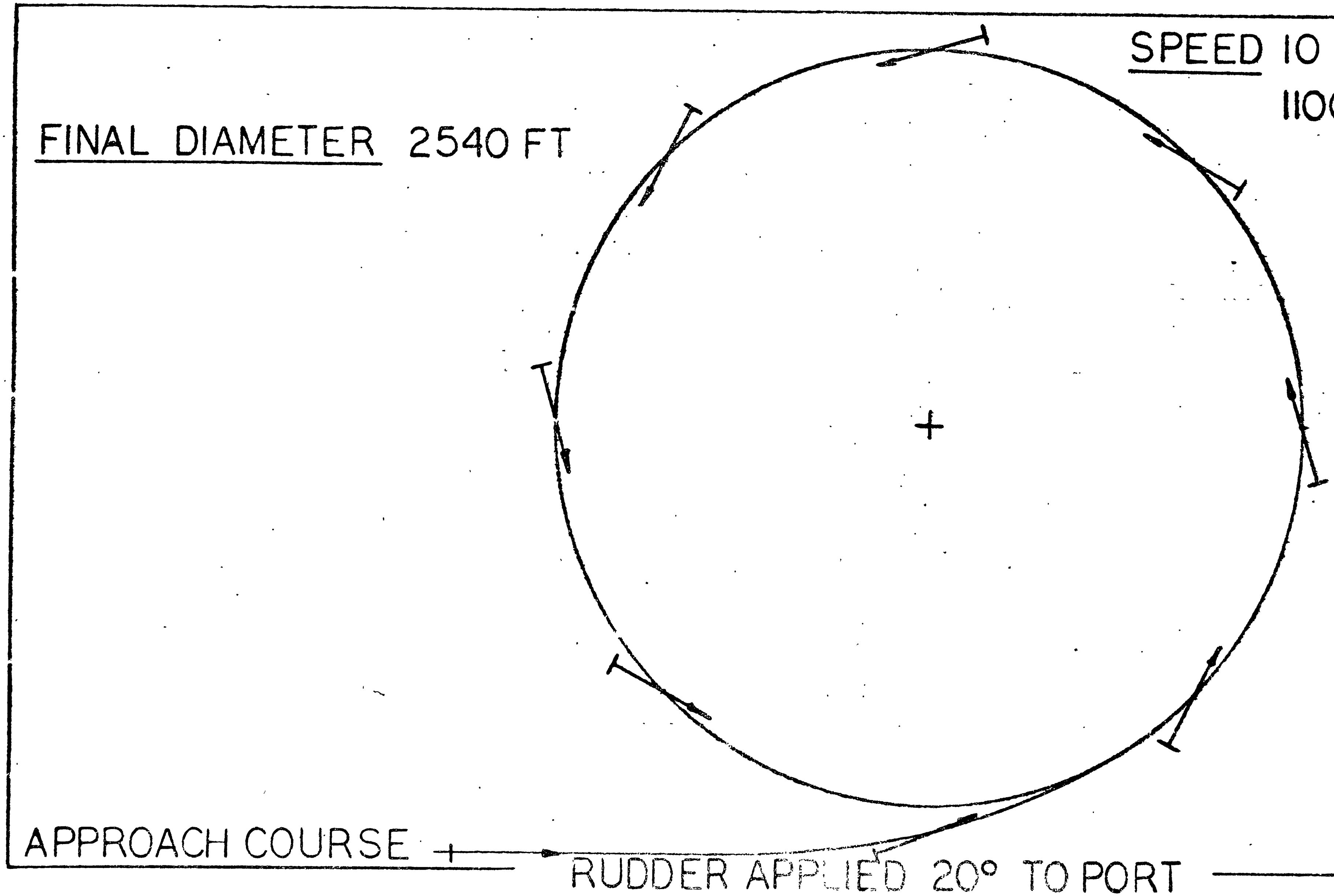

SPEED 10 KTS
1100 RPM
FINAL DIAMETER 2540 FT
APPROACH COURSE
RUDDER APPLIED 20° TO PORT

FIG 22

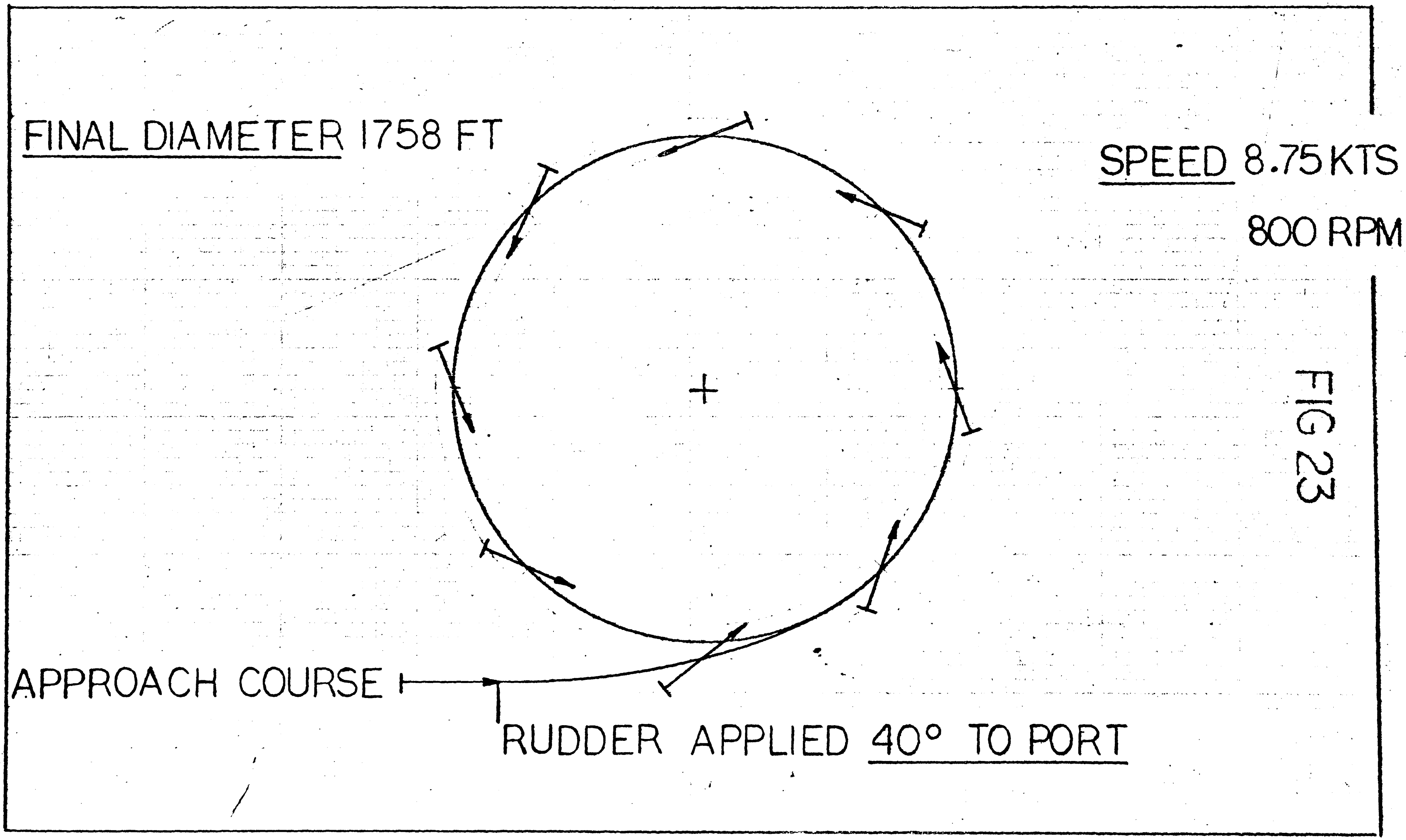

FINAL DIAMETER 1758 FT
SPEED 8.75 KTS
800 RPM
APPROACH COURSE
RUDDER APPLIED 40° TO PORT

FIG 23

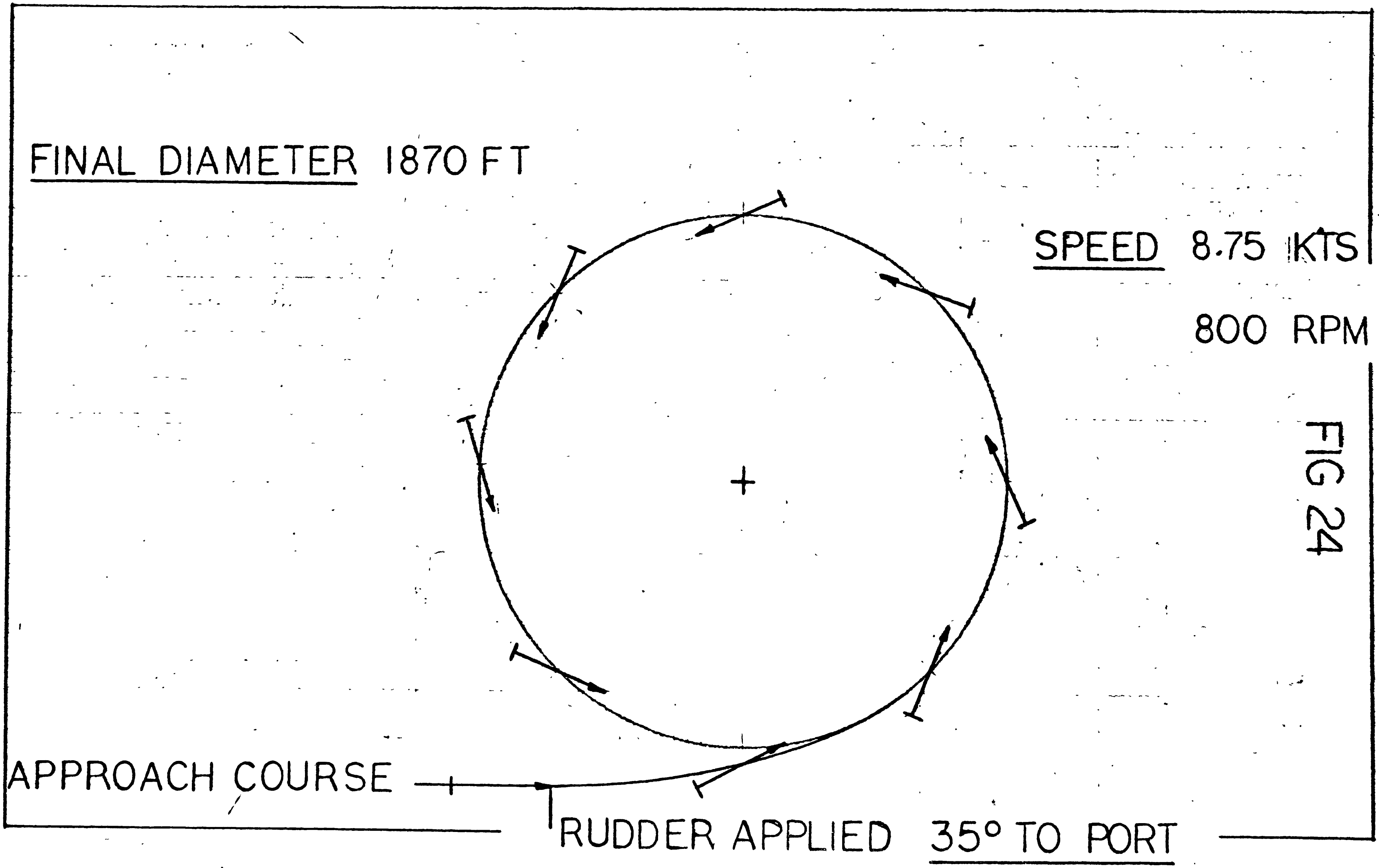
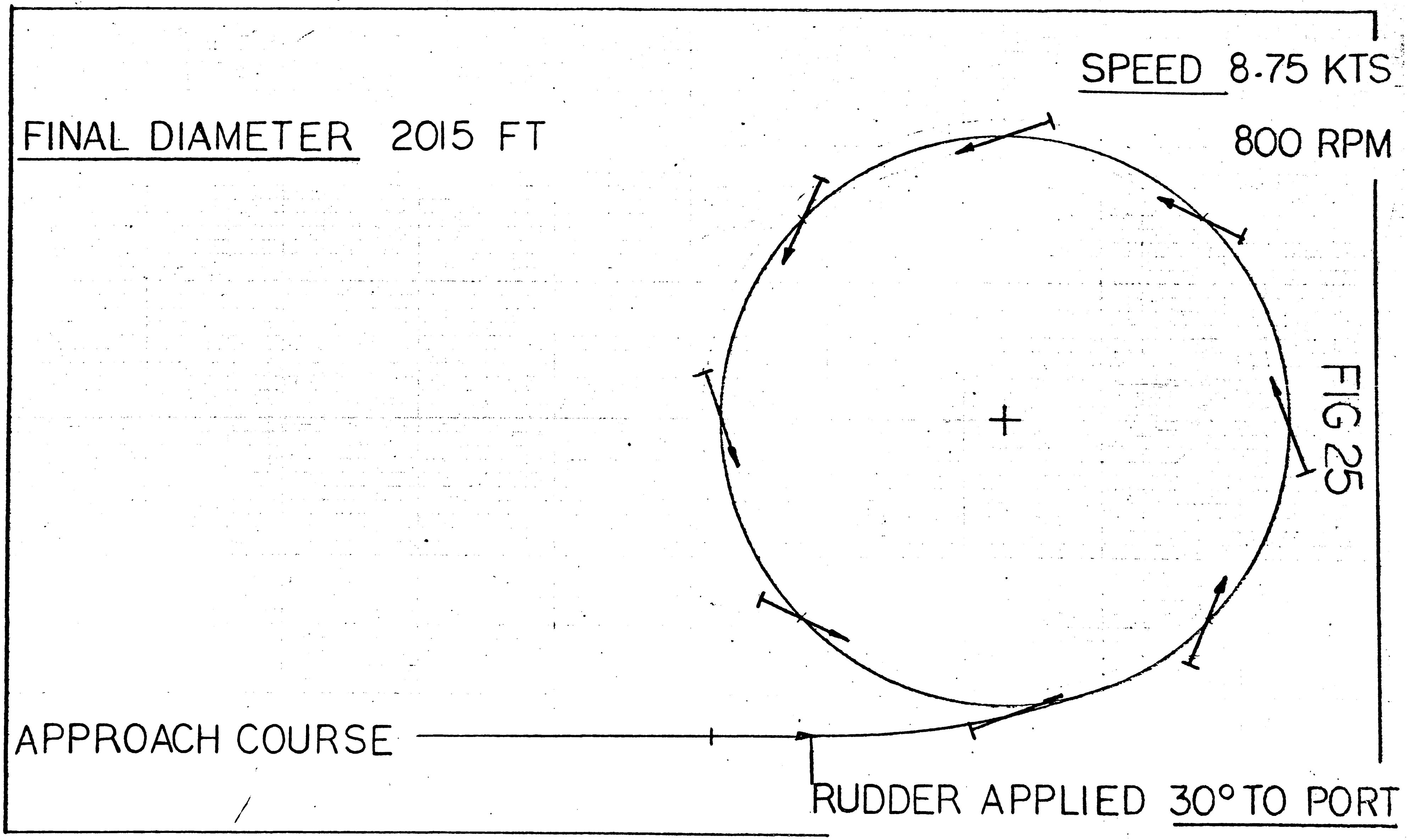

FINAL DIAMETER 1870 FT
SPEED 8.75 KTS
800 RPM
APPROACH COURSE
RUDDER APPLIED 35° TO PORT

FIG 24



SPEED 8.75 KTS
FINAL DIAMETER 2015 FT
800 RPM
APPROACH COURSE
RUDDER APPLIED 30° TO PORT

FIG 25

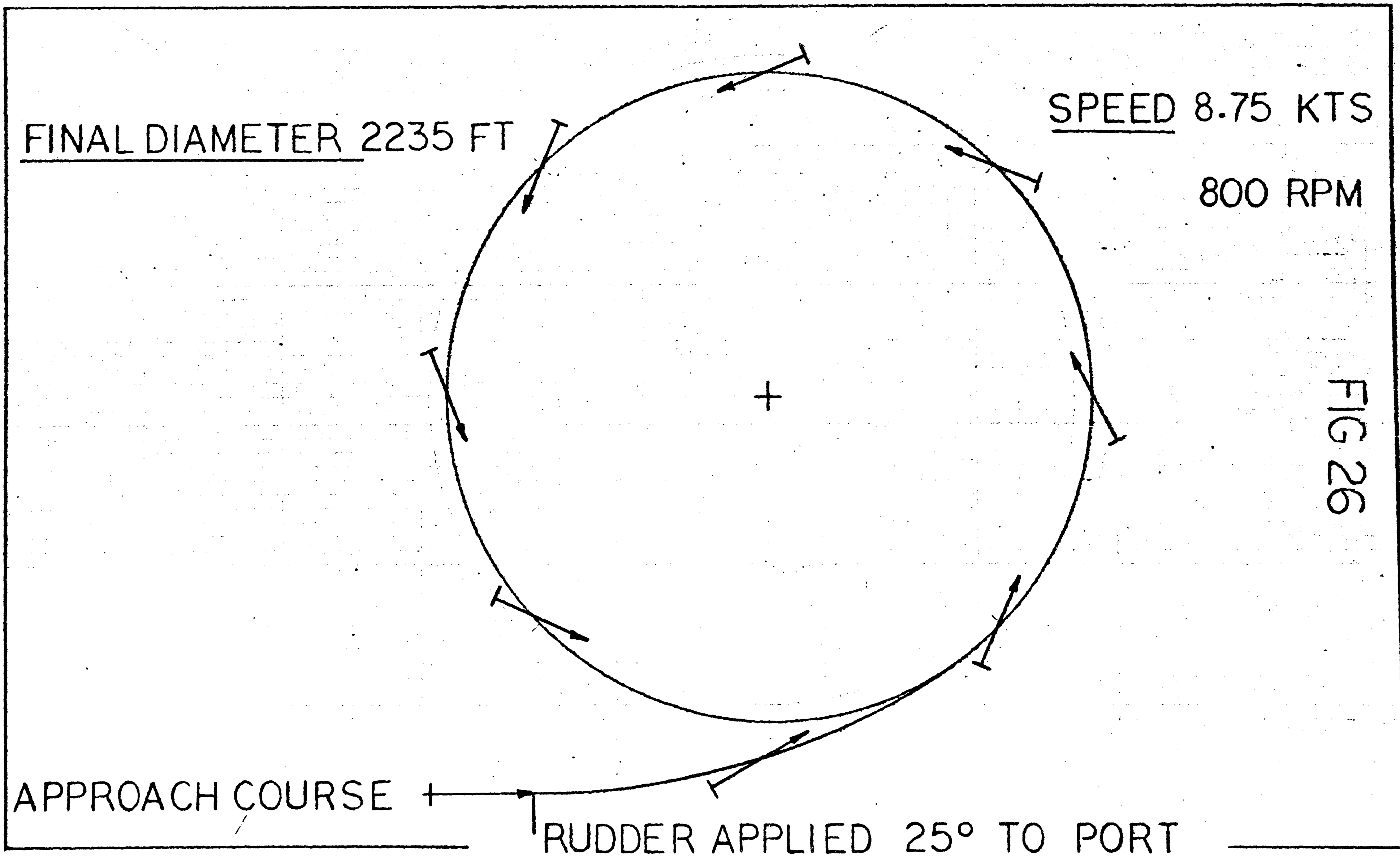
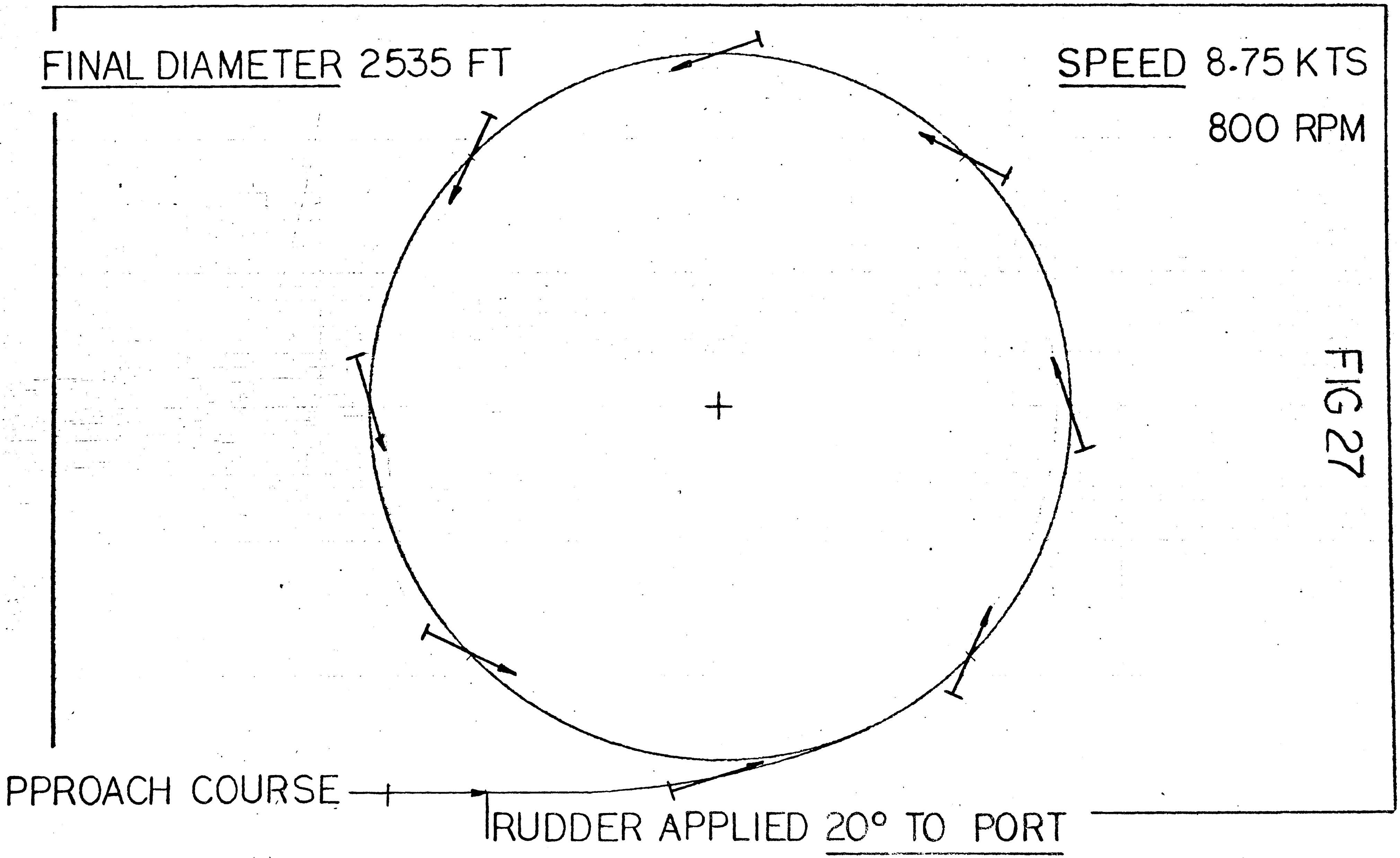

FINAL DIAMETER 2235 FT
SPEED 8.75 KTS
800 RPM
APPROACH COURSE
RUDDER APPLIED 25° TO PORT

FIG 26



FINAL DIAMETER 2535 FT
SPEED 8.75 KTS
800 RPM
PPROACH COURSE
RUDDER APPLIED 20° TO PORT

FIG 27

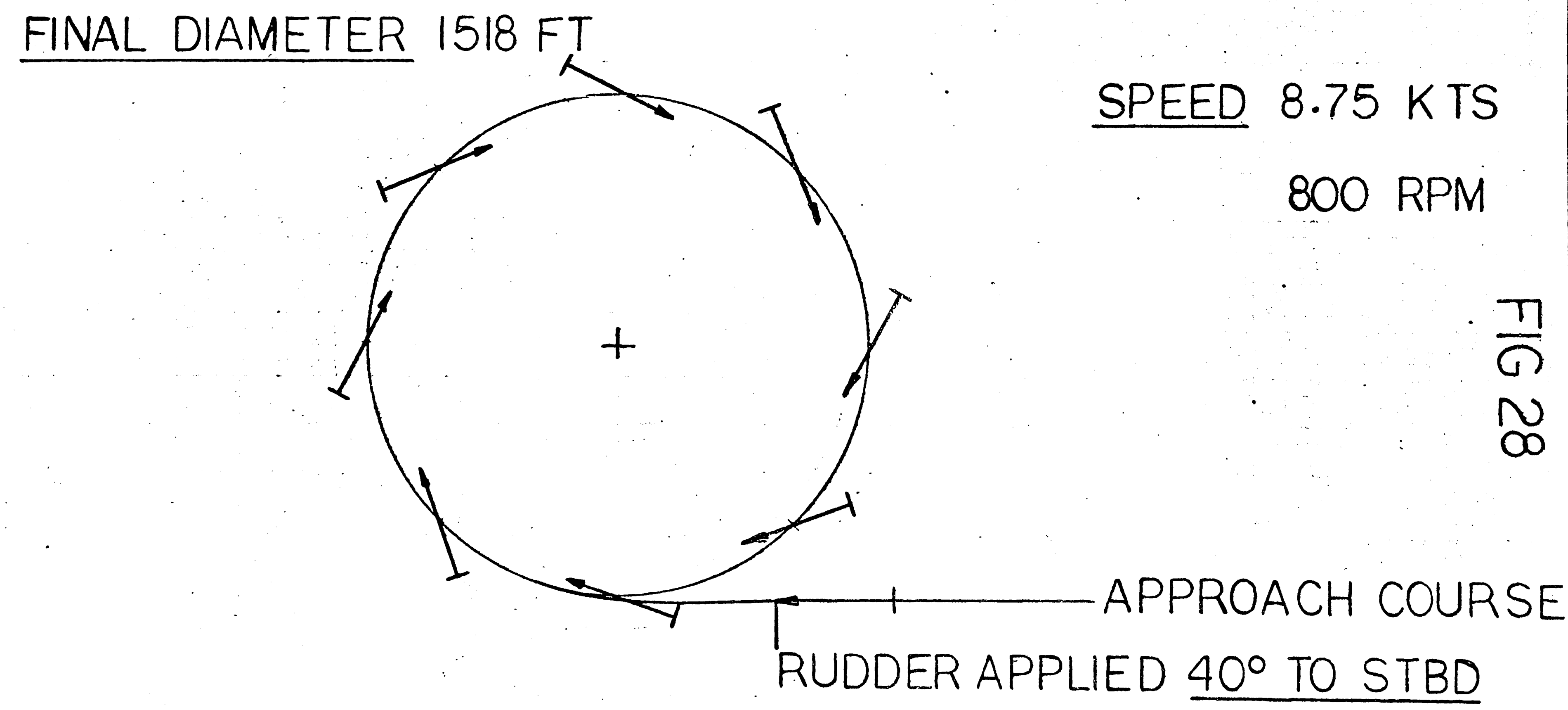

FINAL DIAMETER 1518 FT
SPEED 8.75 KTS
800 RPM
APPROACH COURSE
RUDDER APPLIED 40° TO STBD

FIG 28

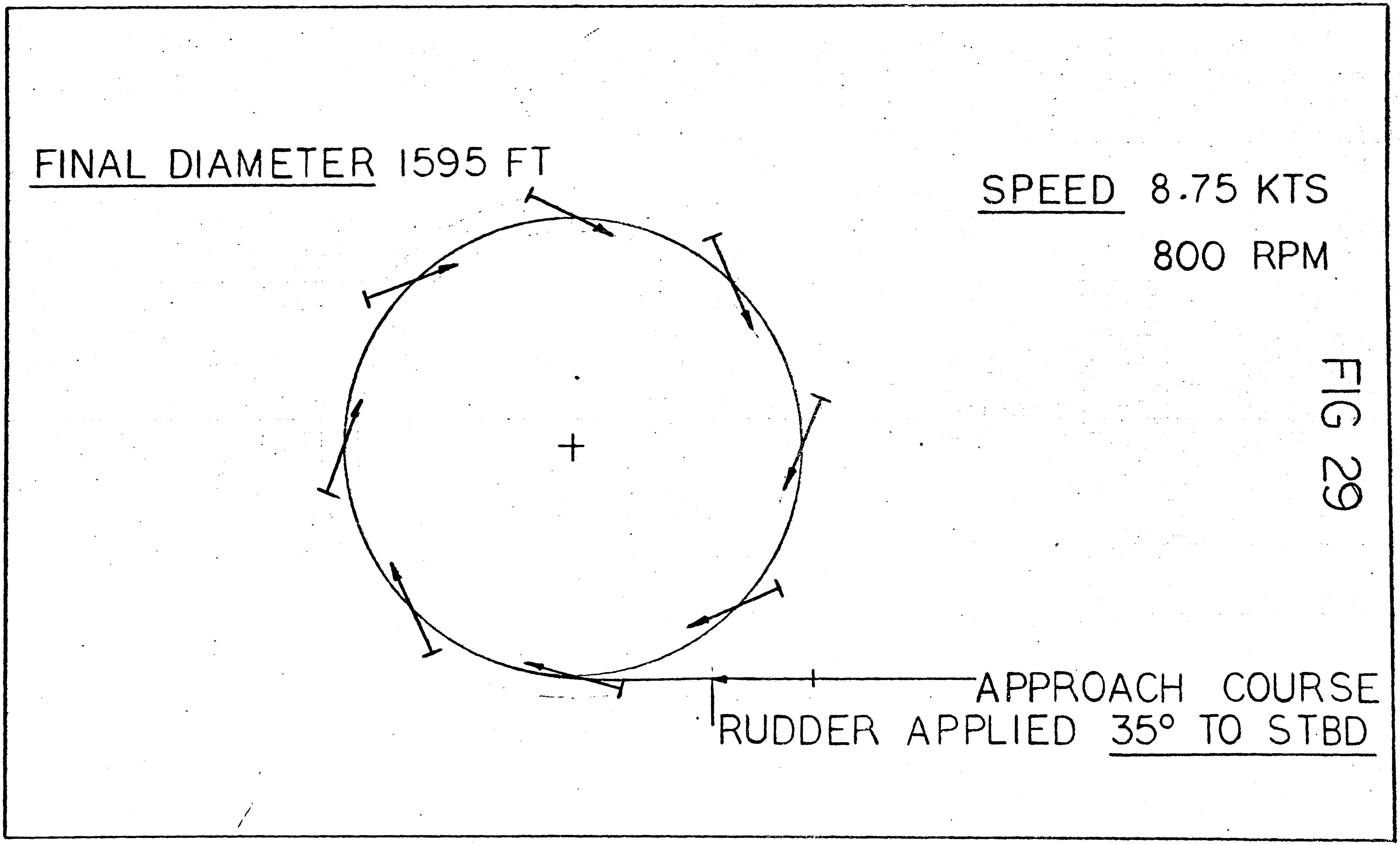
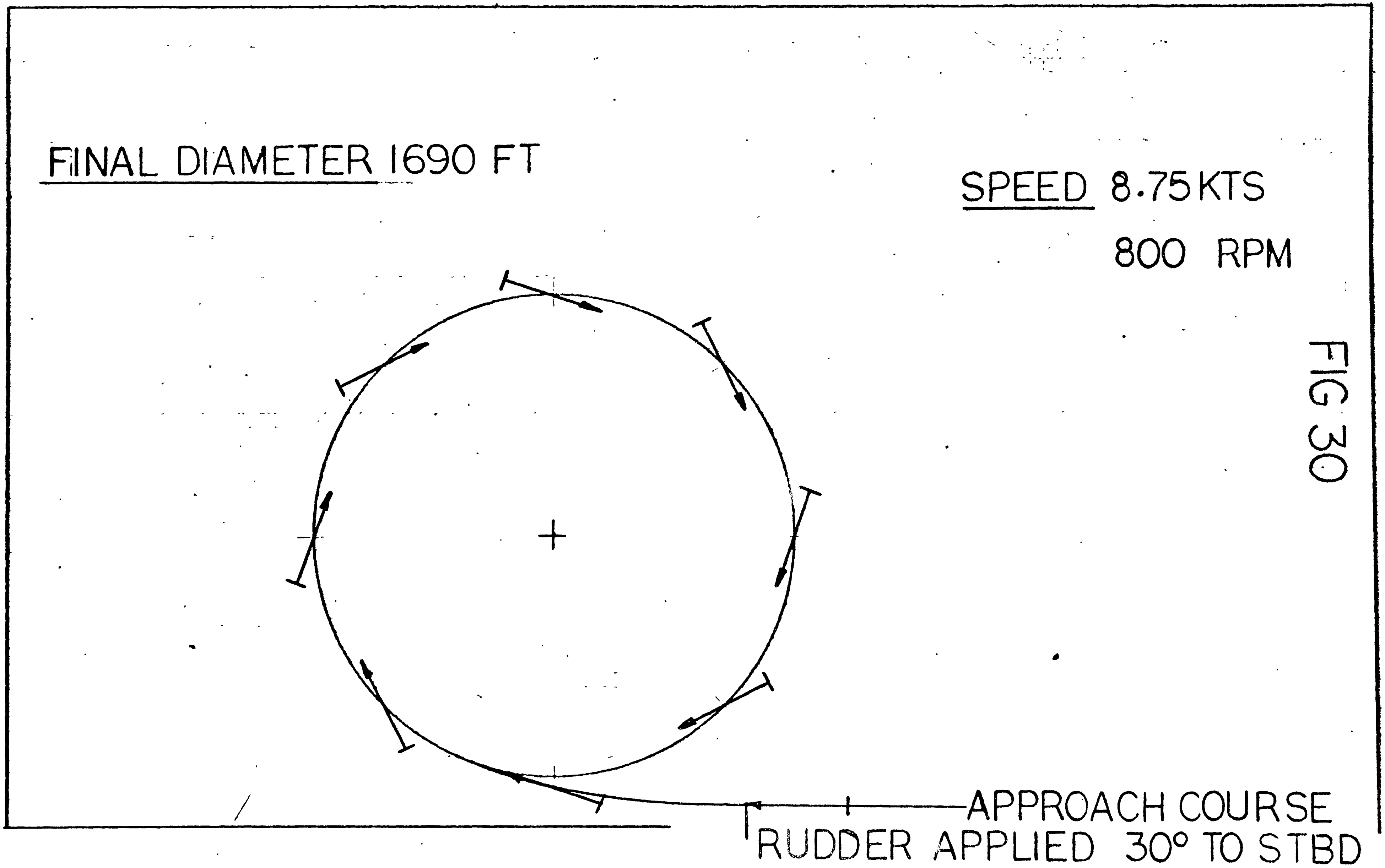

FINAL DIAMETER 1595 FT
SPEED 8.75 KTS
800 RPM
APPROACH COURSE
RUDDER APPLIED 35° TO STBD

FIG 29



FINAL DIAMETER 1690 FT
SPEED 8.75 KTS
800 RPM
APPROACH COURSE
RUDDER APPLIED 30° TO STBD

FIG 30

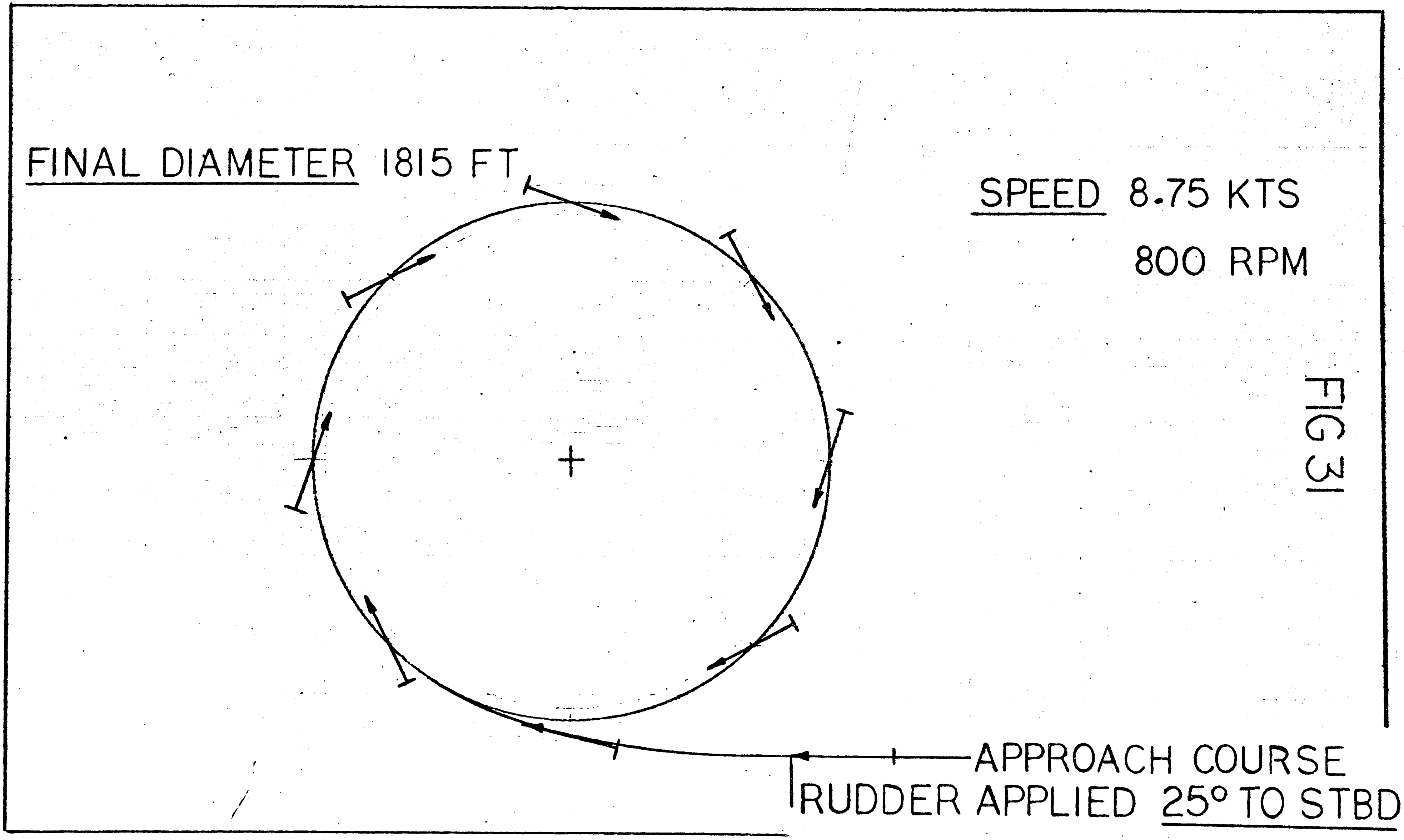

FINAL DIAMETER 1815 FT
SPEED 8.75 KTS
800 RPM
APPROACH COURSE
RUDDER APPLIED 25° TO STBD

FIG 31

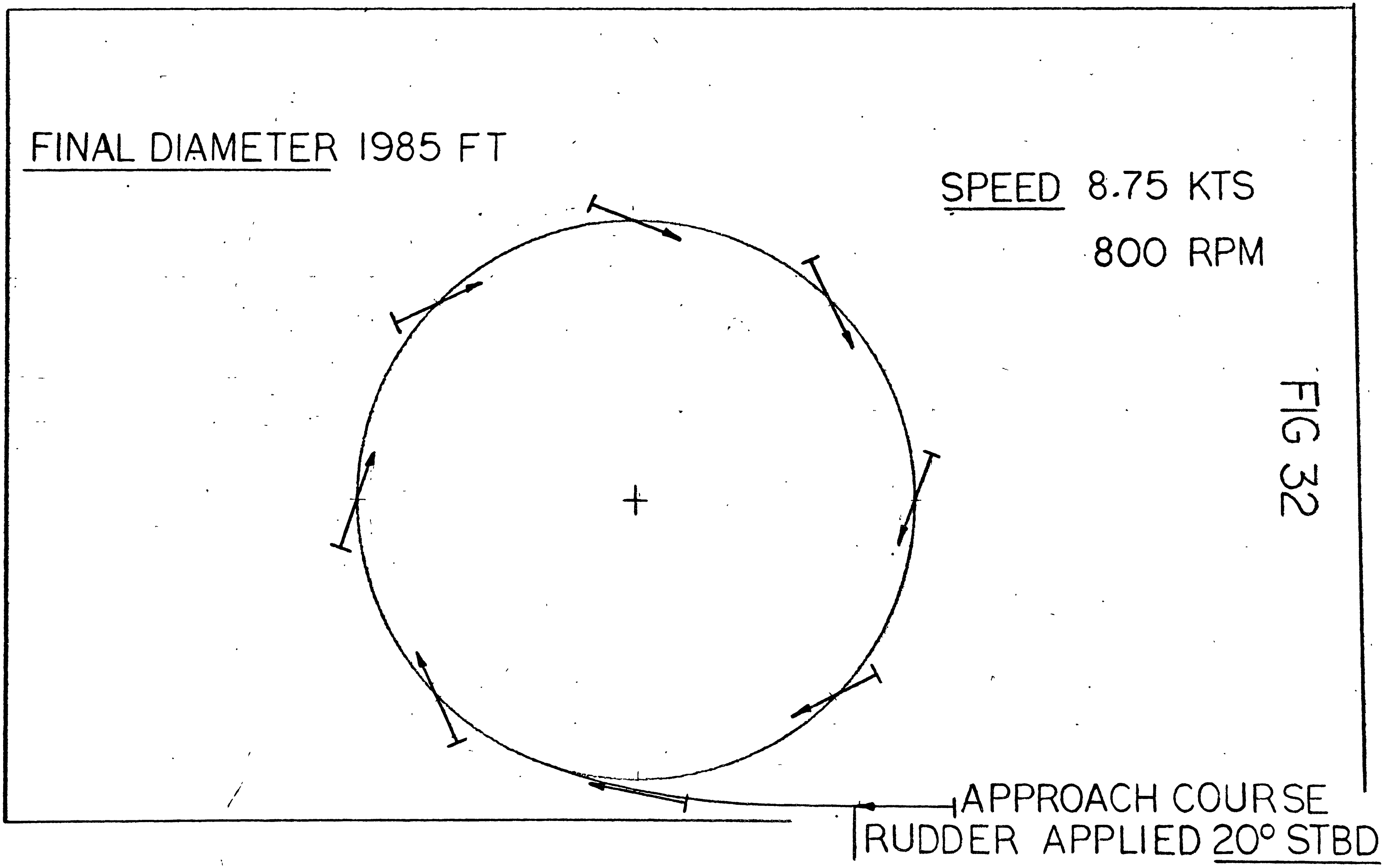

FINAL DIAMETER 1985 FT
SPEED 8.75 KTS
800 RPM
APPROACH COURSE
RUDDER APPLIED 20° STBD

FIG 32

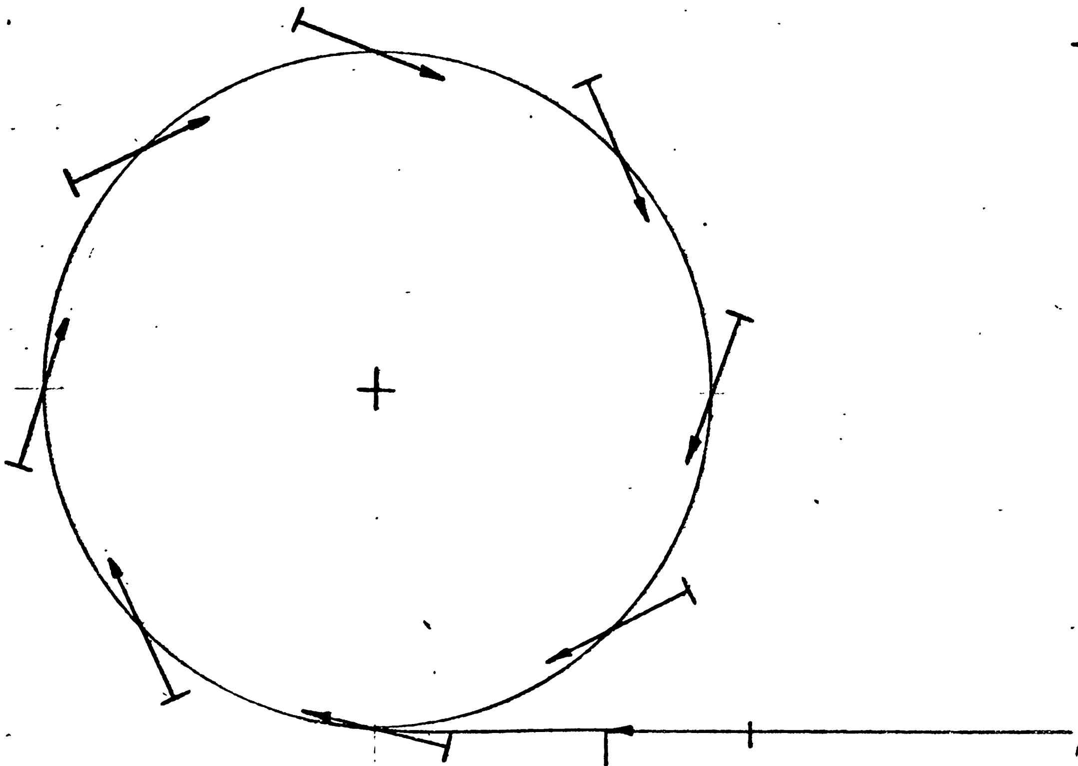

FINAL DIAMETER 1665 FT
SPEED 4.5 KTS
220 RPM
APPROACH COURSE
RUDDER APPLIED 40° TO STBD

FIG 33

FINAL DIAMETER 1765 FT

SPEED 4.5 KTS

220 RPM

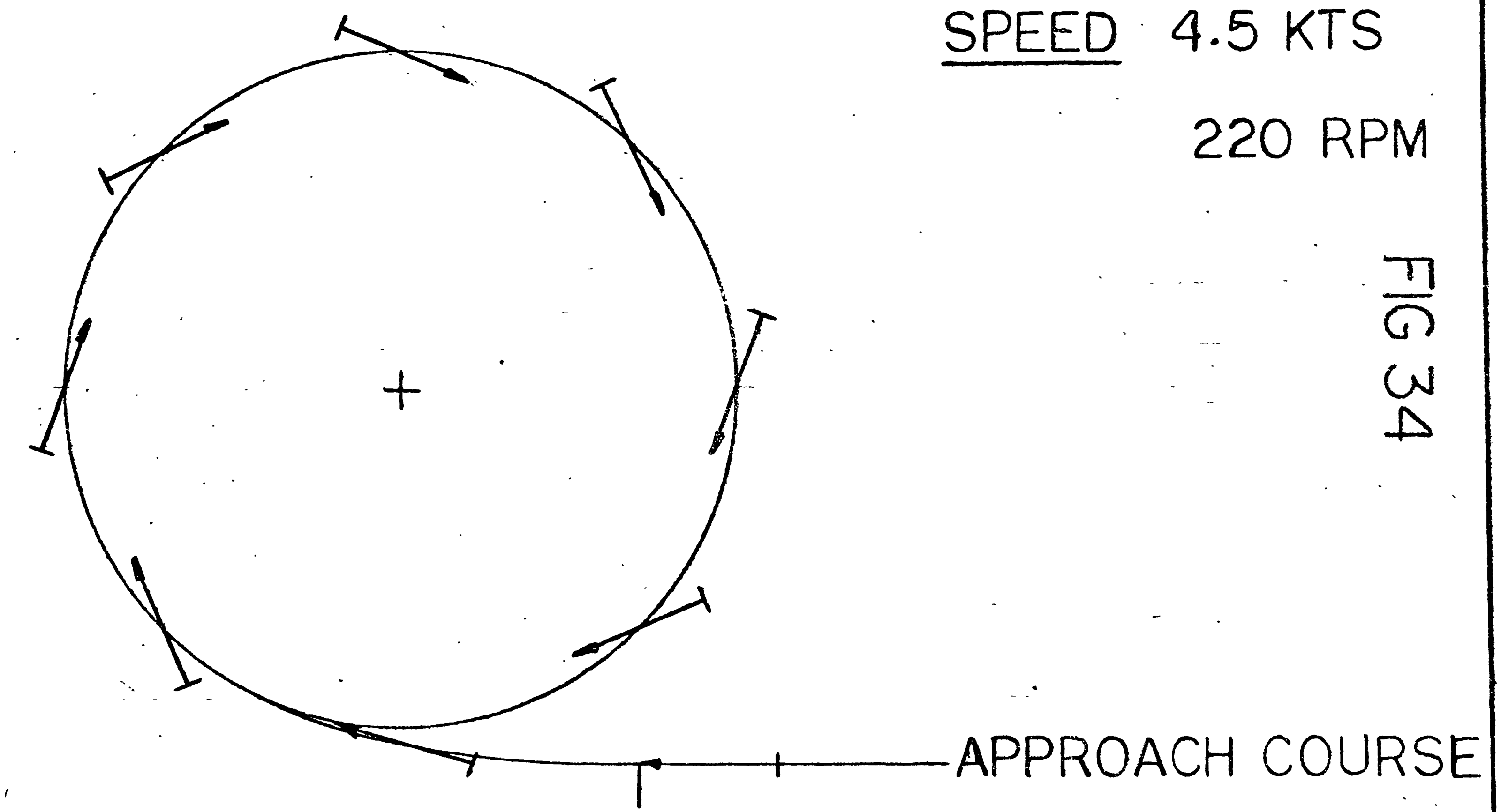


FIG 34

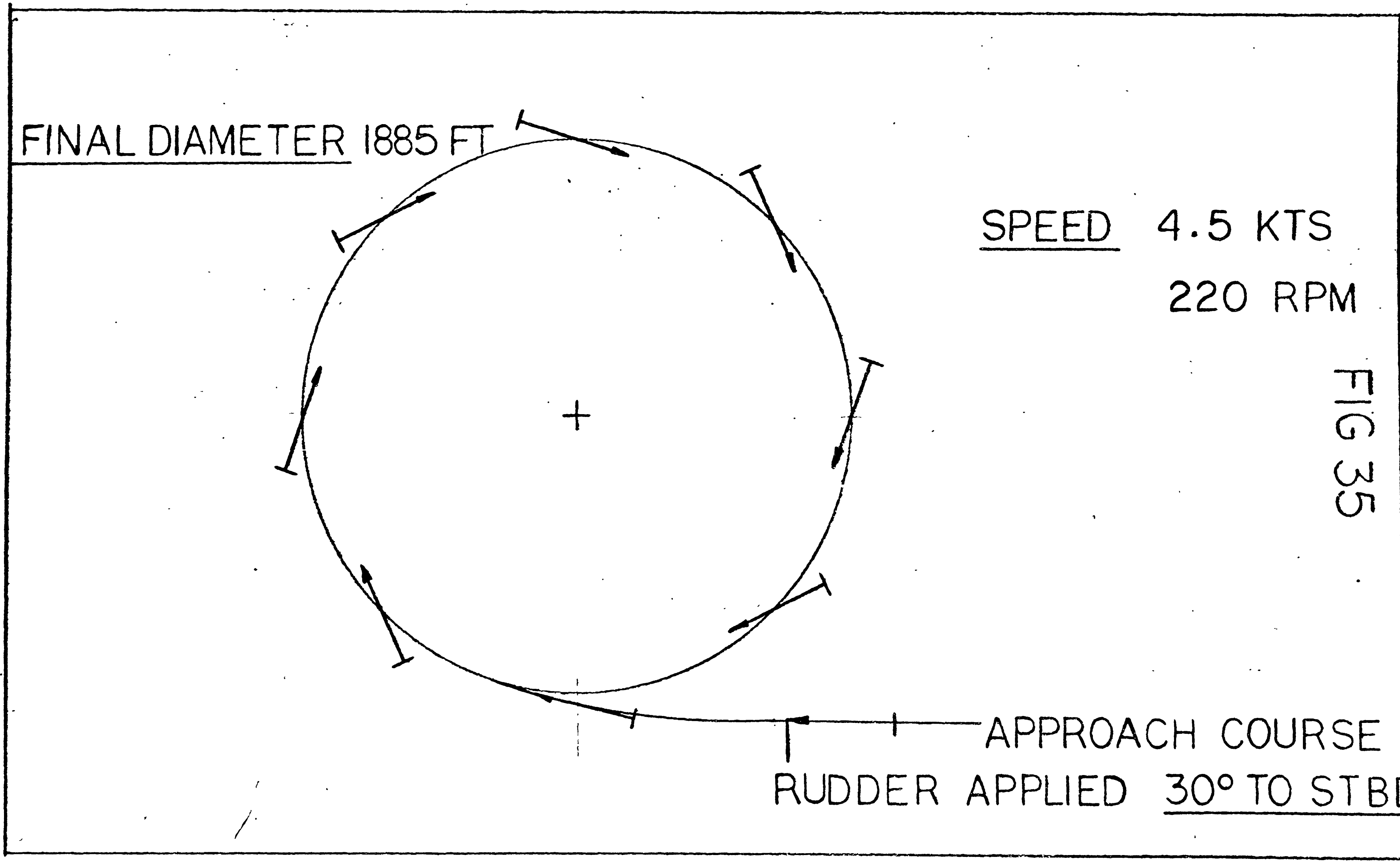

FINAL DIAMETER 1885 FT
SPEED 4.5 KTS
220 RPM
APPROACH COURSE
RUDDER APPLIED 30° TO STBD

FIG 35

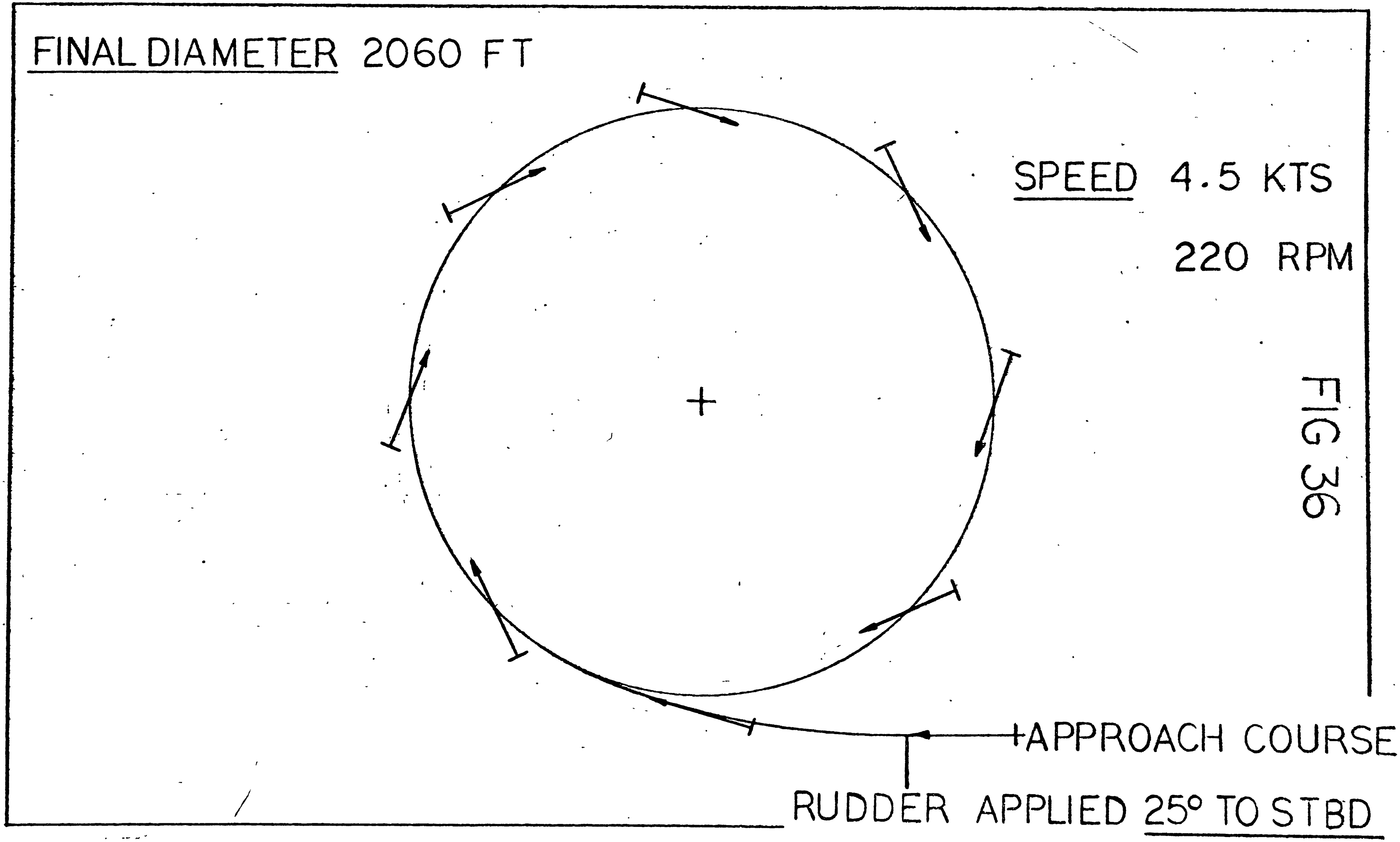

FINAL DIAMETER 2060 FT
SPEED 4.5 KTS
220 RPM
APPROACH COURSE
RUDDER APPLIED 25° TO STBD

FIG 36

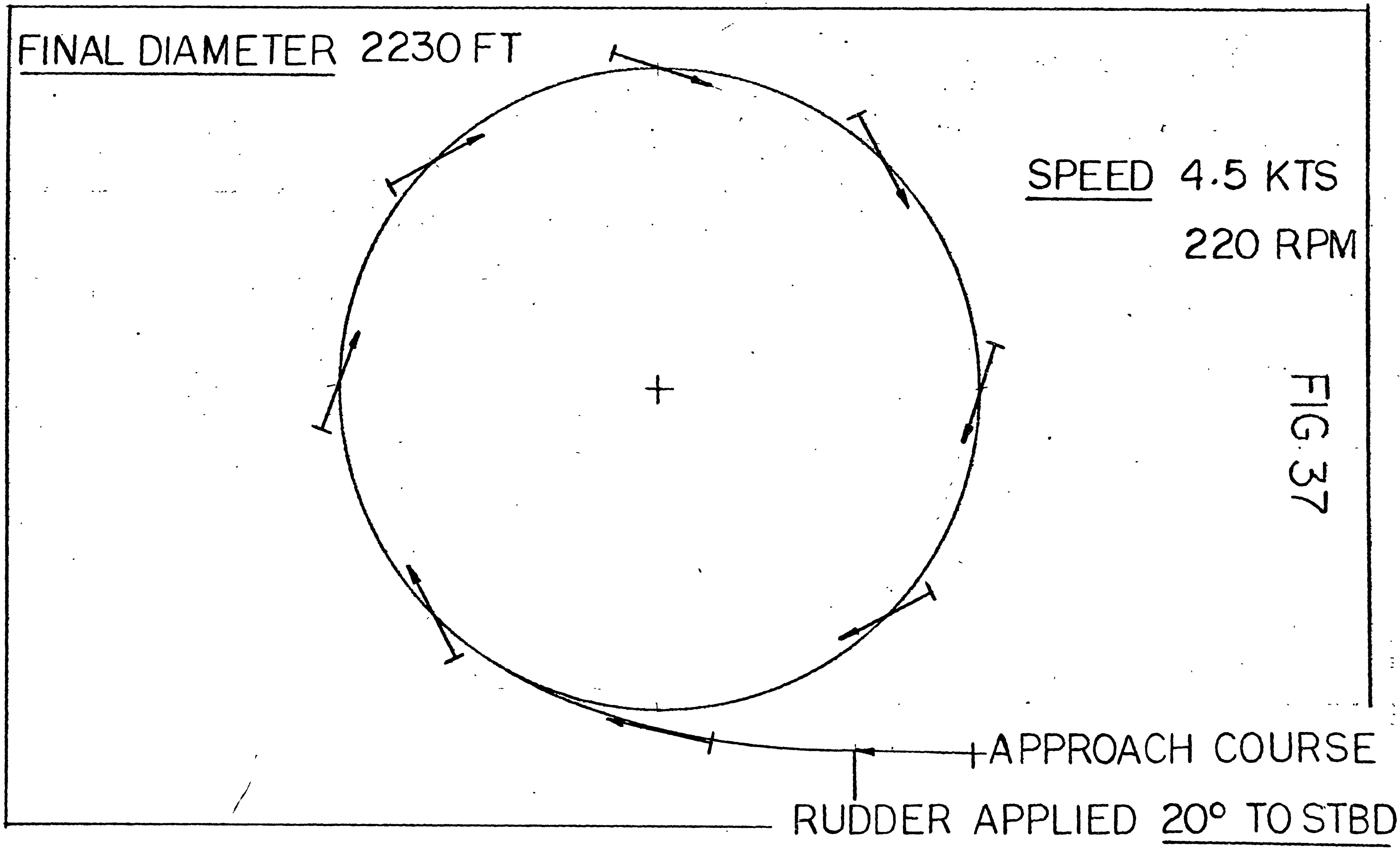
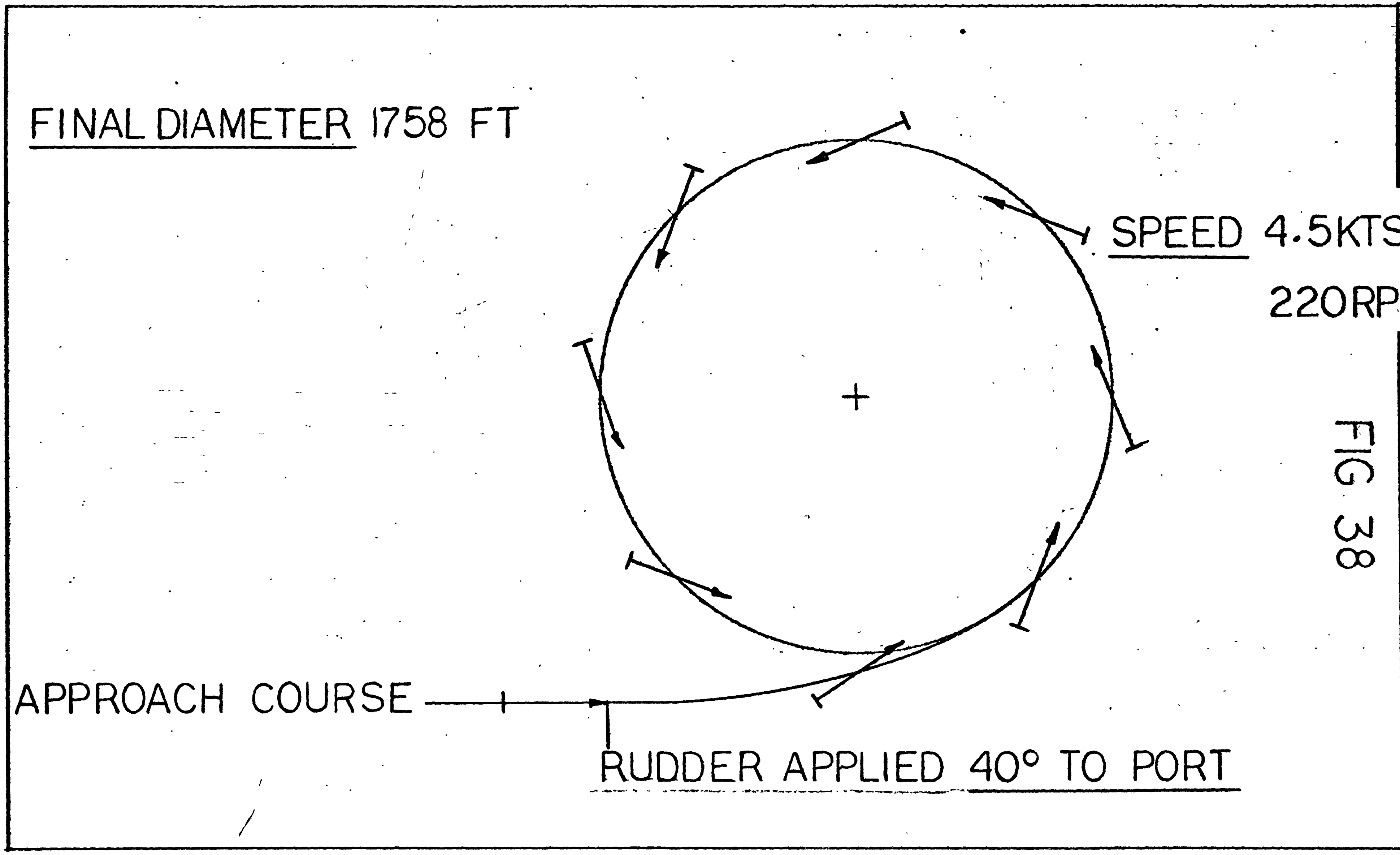
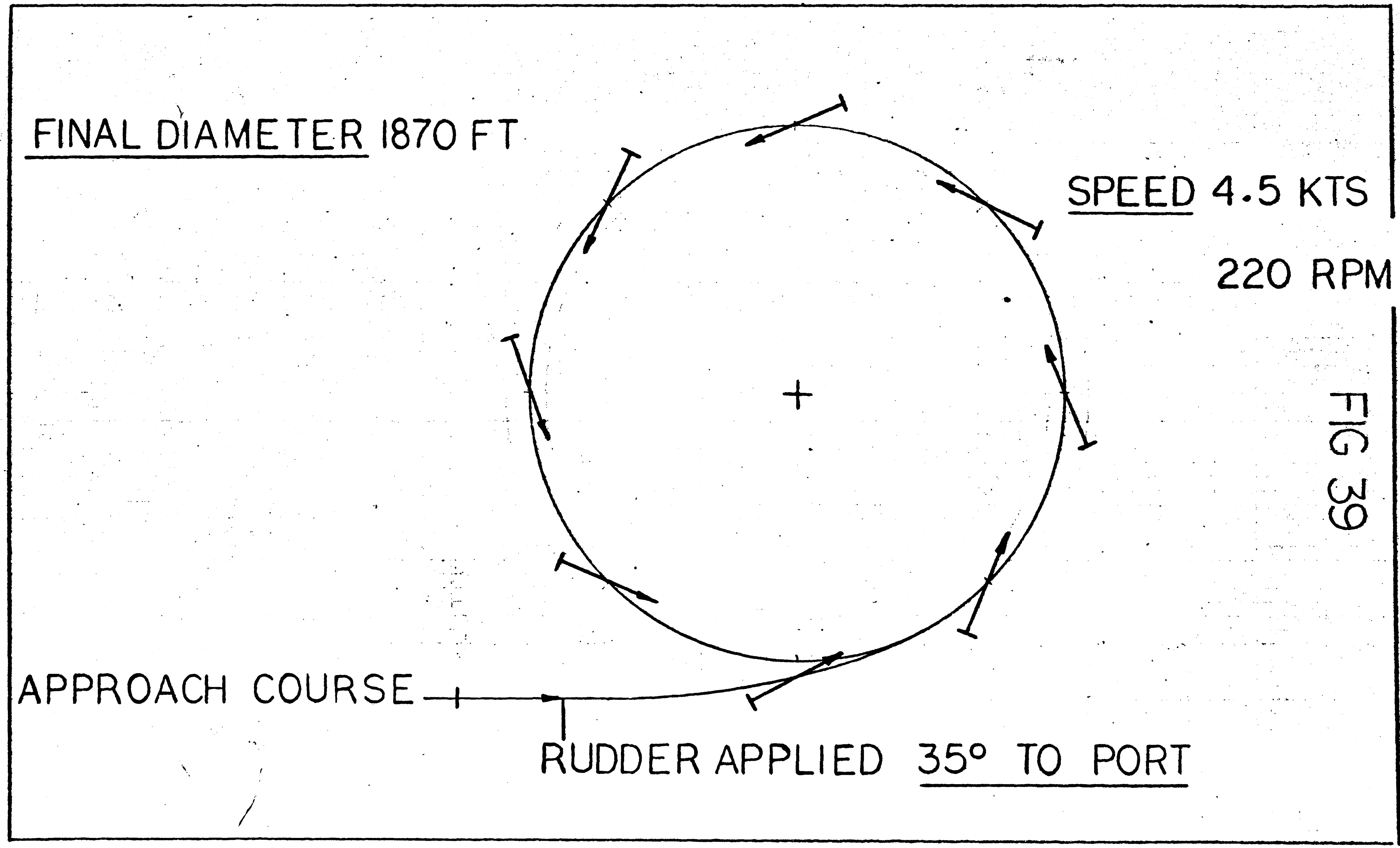

FINAL DIAMETER 2230 FT
SPEED 4.5 KTS
220 RPM
APPROACH COURSE
RUDDER APPLIED 20° TO STBD

FIG. 37



FINAL DIAMETER 1758 FT
SPEED 4.5KTS
220RPM
APPROACH COURSE
RUDDER APPLIED 40° TO PORT

FIG 38



FINAL DIAMETER 1870 FT
SPEED 4.5 KTS
220 RPM
APPROACH COURSE
RUDDER APPLIED 35° TO PORT

FIG 39

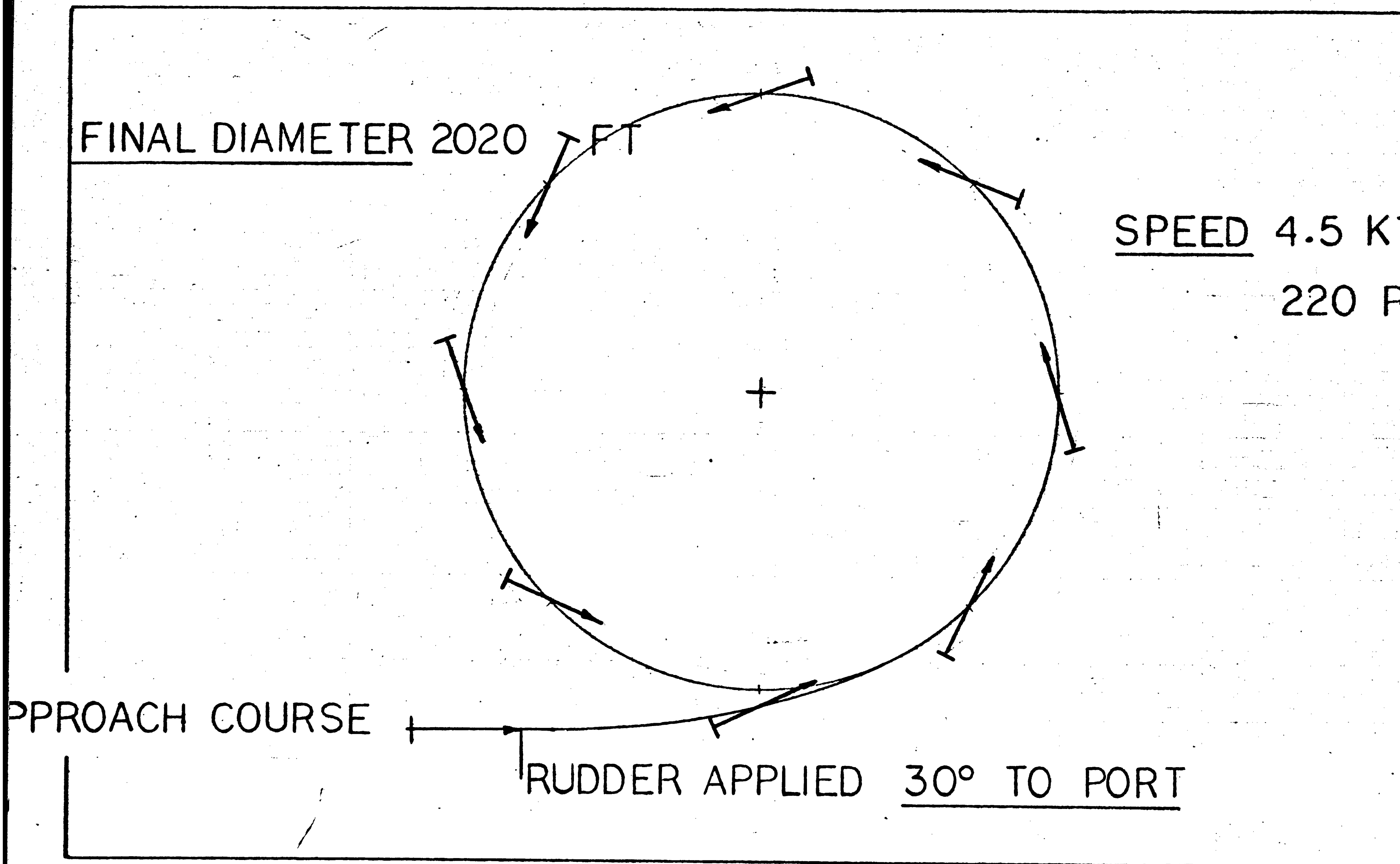

FINAL DIAMETER 2020 FT
SPEED 4.5 KTS
220 RPM
PPROACH COURSE
RUDDER APPLIED 30° TO PORT

FIG 40

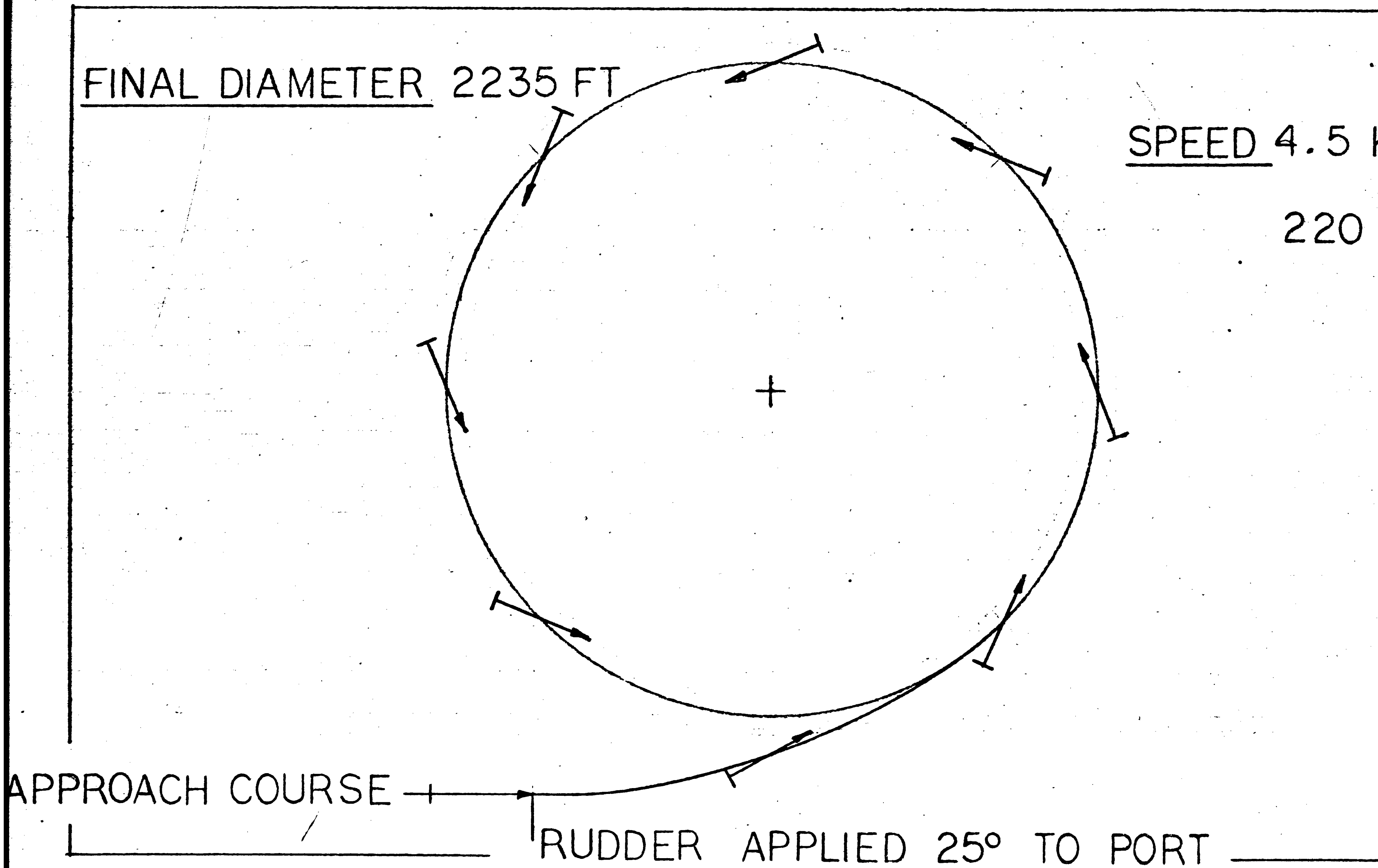
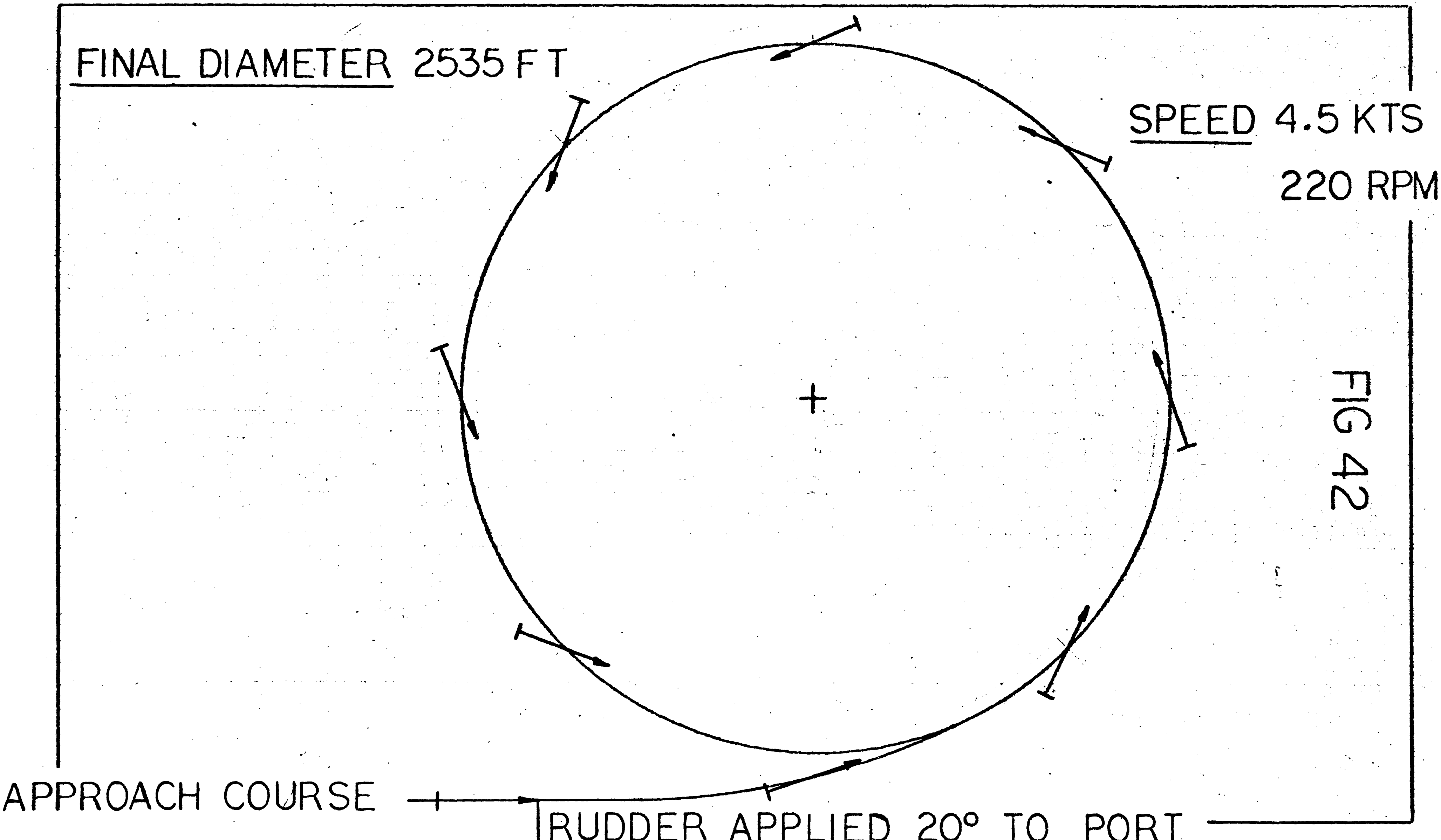

FINAL DIAMETER 2235 FT
SPEED 4.5 KTS
220 RPM
APPROACH COURSE
RUDDER APPLIED 25° TO PORT

FIG 41



FINAL DIAMETER 2535 FT
SPEED 4.5 KTS
220 RPM
APPROACH COURSE
RUDDER APPLIED 20° TO PORT

FIG 42

FIG 43

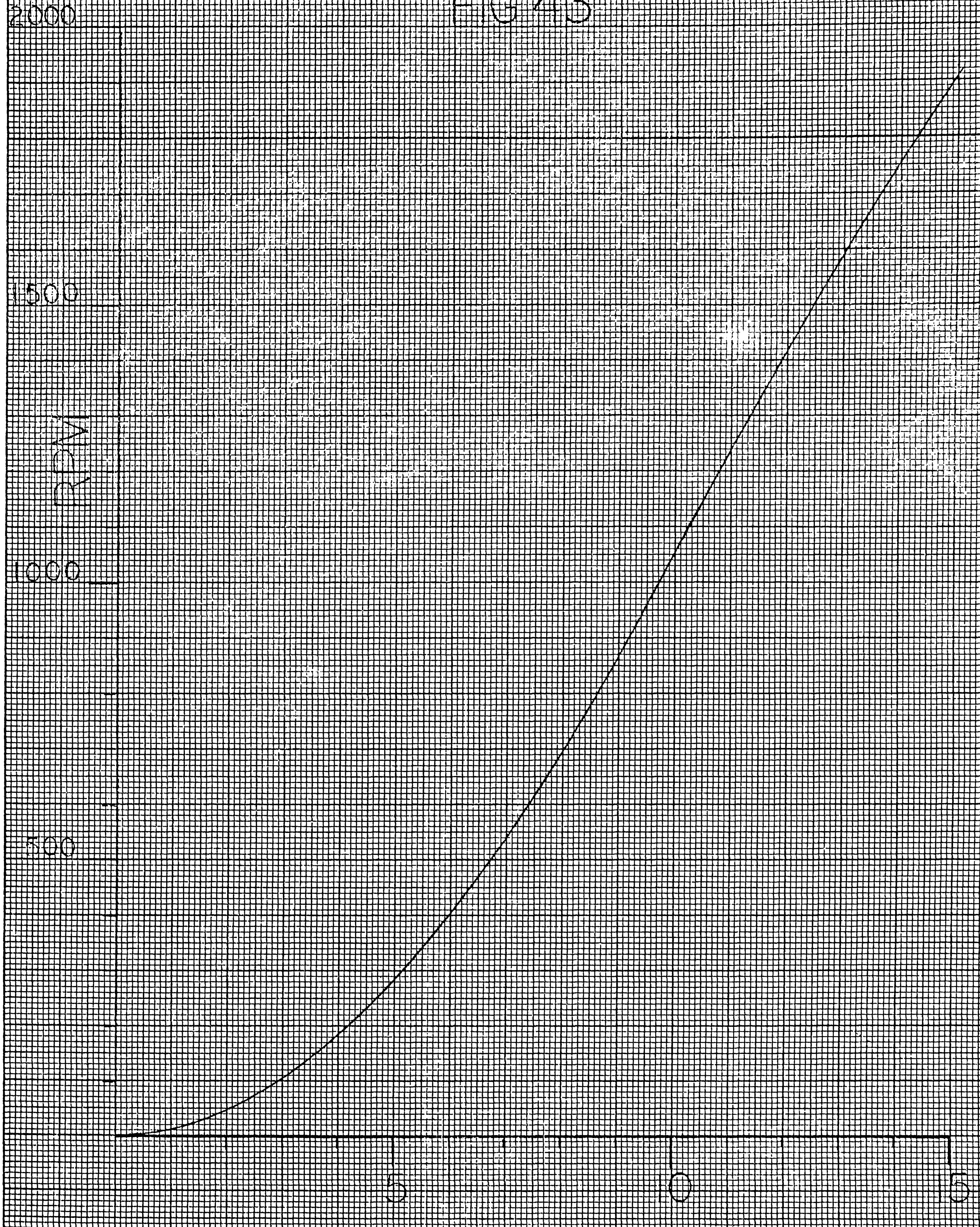
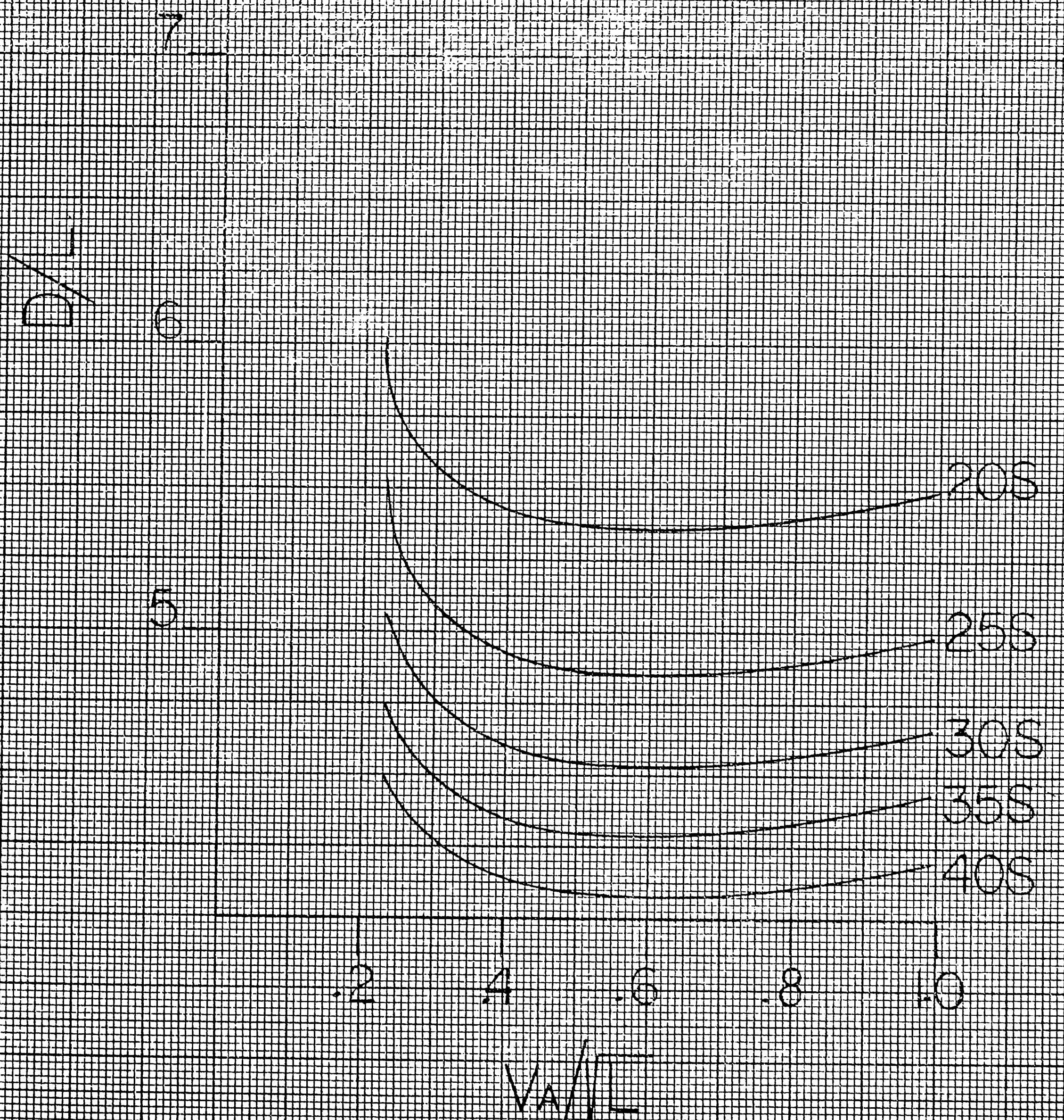
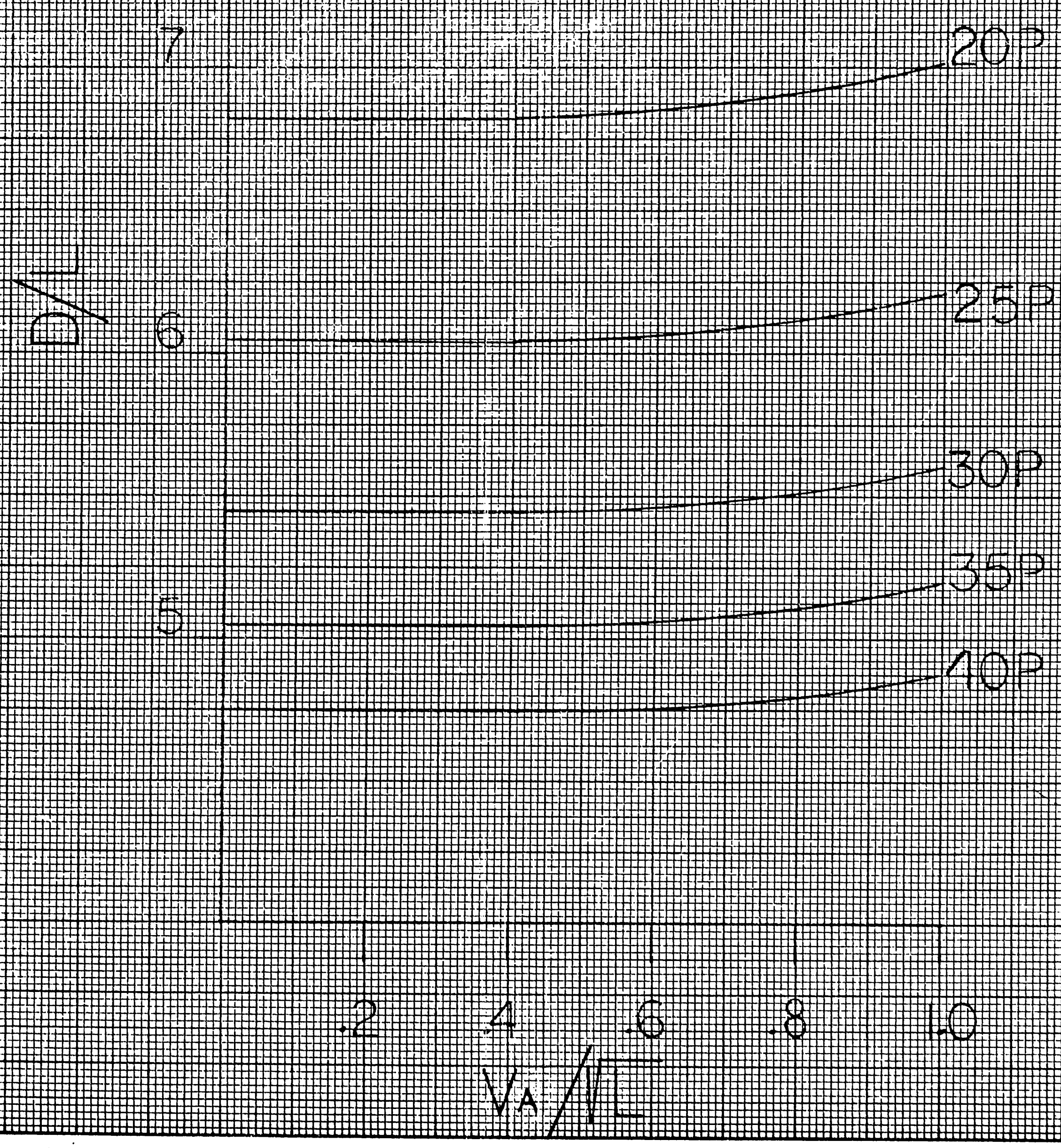


FIG 44



C-24
CORB

FIG 15



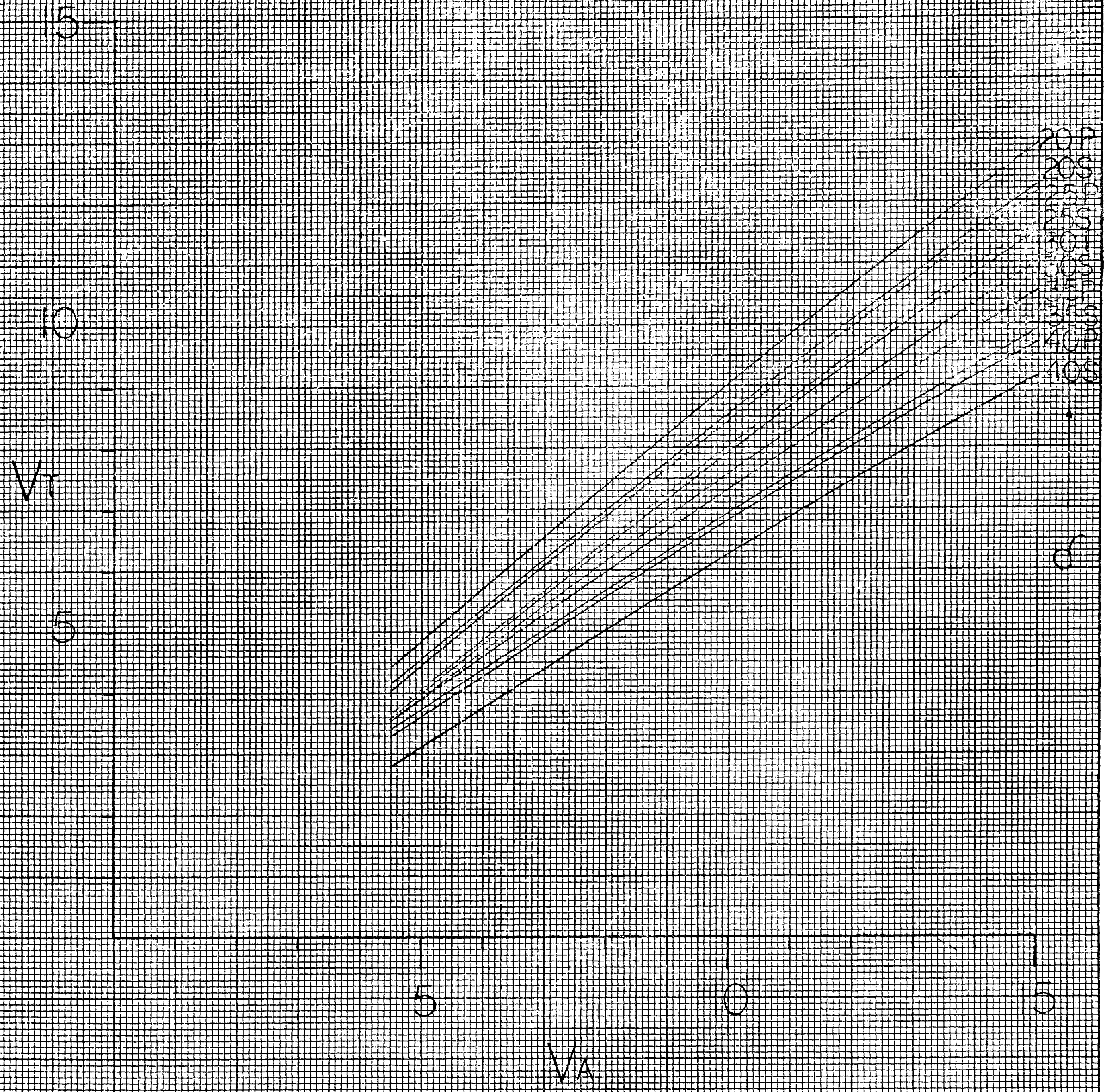


FIG 46