Department of Energy
Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208 - 3621

April 16, 1986

In reply refer to: EPG

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Mr. Douglas Albright
Woodward Governor Company
P.O. Box 7001
Rockford, IL 61125-7001

Dear Mr. Albright:

In our meeting of March 26, 1986, we were provided the opportunity to preview your prototype of an efficiency optimizer for Kaplan turbine governors. Subsequently, Douglas Seely's letter of April 7, 1986, advised that we were reviewing the data which your optimizer compiled on Unit 1 at Clarence Cannon Dam. Our analysis of that data is enclosed and from it we can offer the following comments. First, it does appear that your system can determined the optimum blade-to-gate relationship for a Kaplan turbine with a suitable degree of accuracy. Secondly, as we discussed, your optimizer could be of even additional value if it were programmed to provide trending information which could be used in the diagnostic monitoring of a unit's performance.

The basic data was reviewed and analyzed in a detailed but slightly different manner from your test report. First, both flow and power at their individual test heads were converted to the equivalent values at 82.5 feet by the standard affinity relationships. This procedure of multiplying discharge by the square root of the ratio of common to individual test head, and power by this head ratio to the 3/2 exponent assumes a linearity of these parameters with head. However, this has been found to be an accurate procedure for small changes in head, usually within a range of ± 3 percent. The resulting efficiencies are then the equivalent efficiencies at a constant head of 82.5 feet. This eliminates any inconsistencies in the efficiency value due to minor head fluctuations.

Secondly, although your standard graphical presentation of gate opening (actually gate servo stroke) versus blade angle is utilized as shown on Graph 1, we complemented it with a second graphical procedure shown on Graph 2. On this, the efficiency of each data point in each data set was plotted versus blade angle. Blade angle was selected rather than some other parameter, such as gate opening, because of the spread in its data. Graph 2 was then used to interpolate for the exact point of peak efficiency to be marked on Graph 1, rather than simply noting the particular data point with the highest efficiency. This second procedure provides up to 2 percent increase in the accuracy of identifying the blade angle at peak efficiency.

As to the best manner to graphically present this data, I do like the gate opening versus blade angle with efficiency contour overlay method of Don Sachs'. An additional use of Graph 2 is to obtain the loci of these isoefficiency contours to overlay on Graph 1. It is also informative on Graph 1 to show both the "as found" cam as well as the optimum cam.

One additional feature that probably would help demonstrate the value of this efficiency optimization would be an auxiliary plot of power versus efficiency increase between the "as found" and optimum cams as shown on the upper left of Graph 1. Again, Graph 2 may be utilized to obtain this plot. It is noted, however, that for this particular data, the plots of efficiency versus blade angle on Graph 2 show significant variations of several percent for the peak values. From this, it appears that, although a data set may be consistent within itself, they are not consistent one to another.

There are several possible explanations for this, the most likely being changes in some data or instrumentation calibration. Due to this variation, uniform isoefficiency contours could not be determined and plotted on Graph 1. This does demonstrate the need for a consistent test setup with constant or compensating calibrations. Even with these variations, however, the auxiliary plot on Graph 1 still shows the efficiency of this particular turbine- generator can be increased an average of 0.6 percent by shifting to the optimum cam.

It is observed on Graph 1 that half of the constant power data sets were all taken with 5 MW of full power. This certainly demonstrates the repeatability of your optimizer's solution but also points out the need for the tested unit to be operated uniformly over its full power range to accurately define the complete optimum blade-to-gate cam.

It is noted that for each data set, the power is not held exactly constant, but has a little variation. As near as can be determined, however, this did not appear to particularly effect the accuracy of the solution. On the other hand, some of the constant power, blade-to-gate, curves on Graph 1 show abrupt changes in curvatures. This is interpreted to be due to hysteresis in the blade control circuit. In other words, on this test your optimizer was instrumented to record where the governor was telling the blades to go rather than where the blades actually were. This undoubtedly caused some of the error in locating the peak efficiency points to define the optimum cam curve as well as the variations in the auxiliary plot of efficiency increase versus power.

Presumably, if you instrumented off the indicating surface of the blade servo rod (inner oil pipe) in the oil head or even the blade restoring cable, these constant power curves would exhibit a more uniform curvature and the errors would be reduced. In fact, if your instrumented off either one as well as keeping your present instrumentation, your optimizer could also be used to diagnose the mechanical hysteresis in the turbine blade positioning control. It is of interest to note that on this particular generating unit most of the sudden changes in curvature in blade position occur between 60 and 65 percent gate opening. This could indicate some kind of a "rough spot" in the positioning control.

Since Don Sachs apparently only indexed this unit at 75 foot head, I am sure he would appreciate receiving these results of the optimum blade-to-gate relation for 82.5 feet.

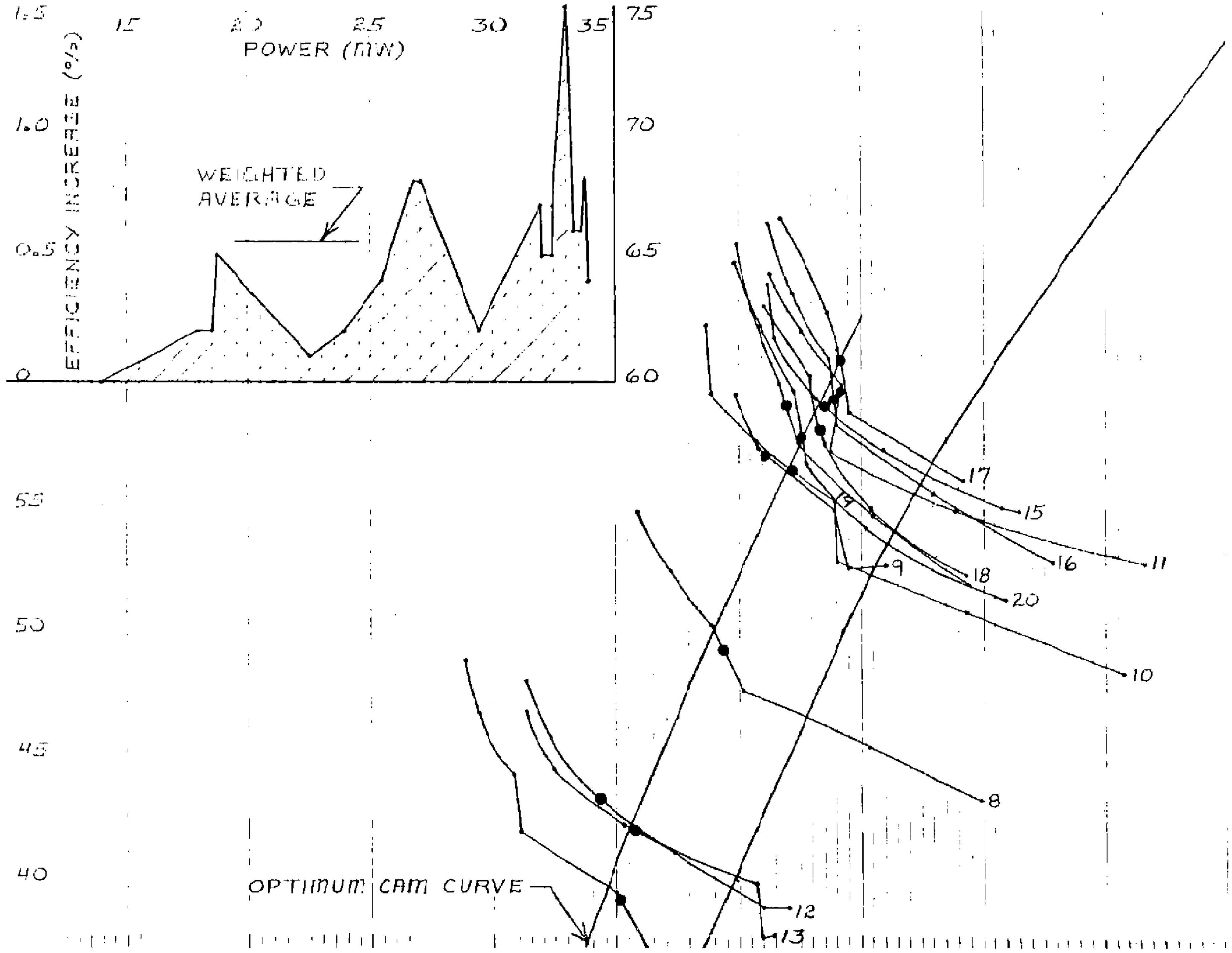
In view of the foregoing, we continue to maintain our interest in testing and demonstrating your optimizer here in the Pacific Northwest as part of our hydro system efficiency improvement program.

Sincerely,

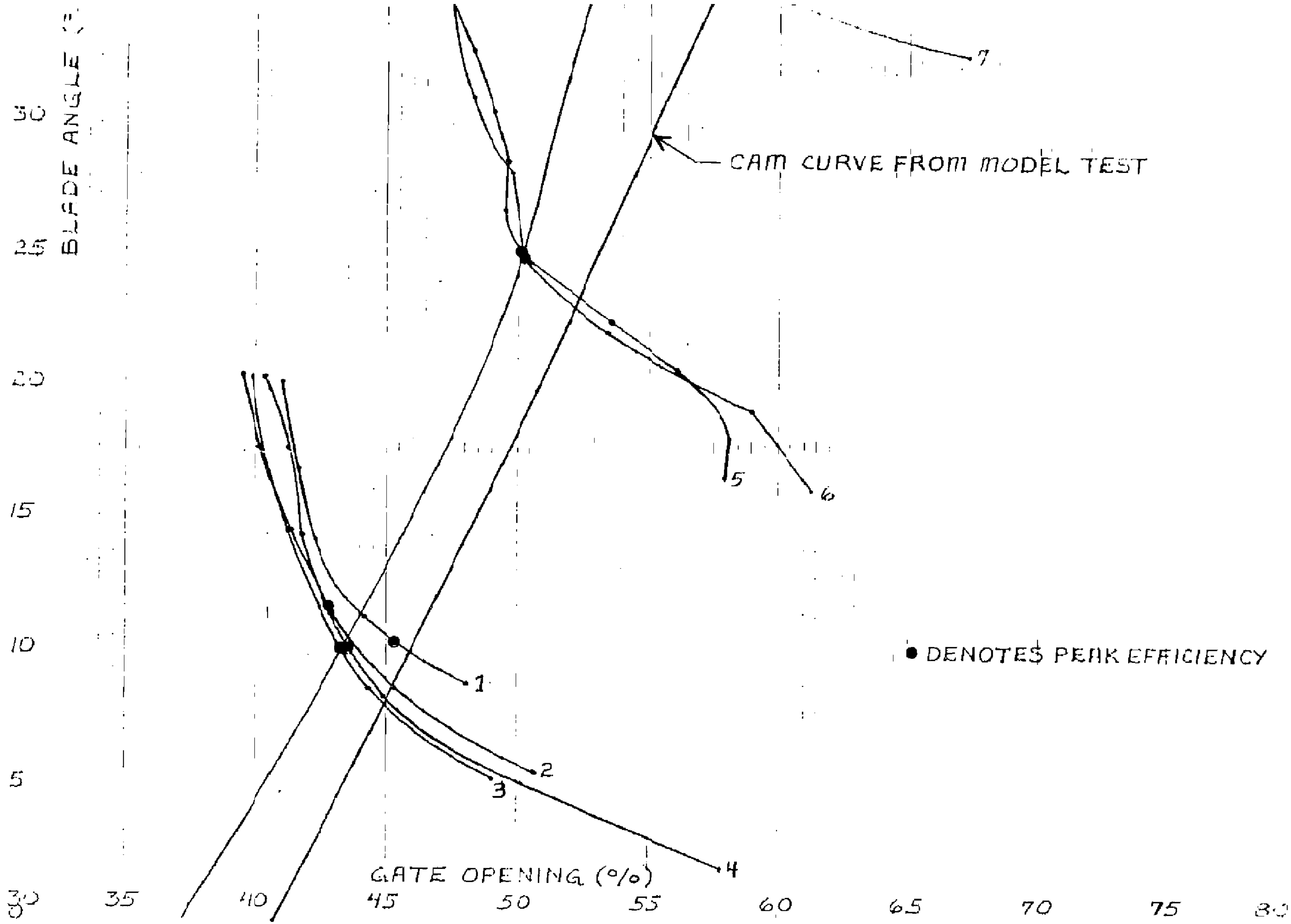
Lee H. Sheldon

Lee H. Sheldon
Mechanical Engineer

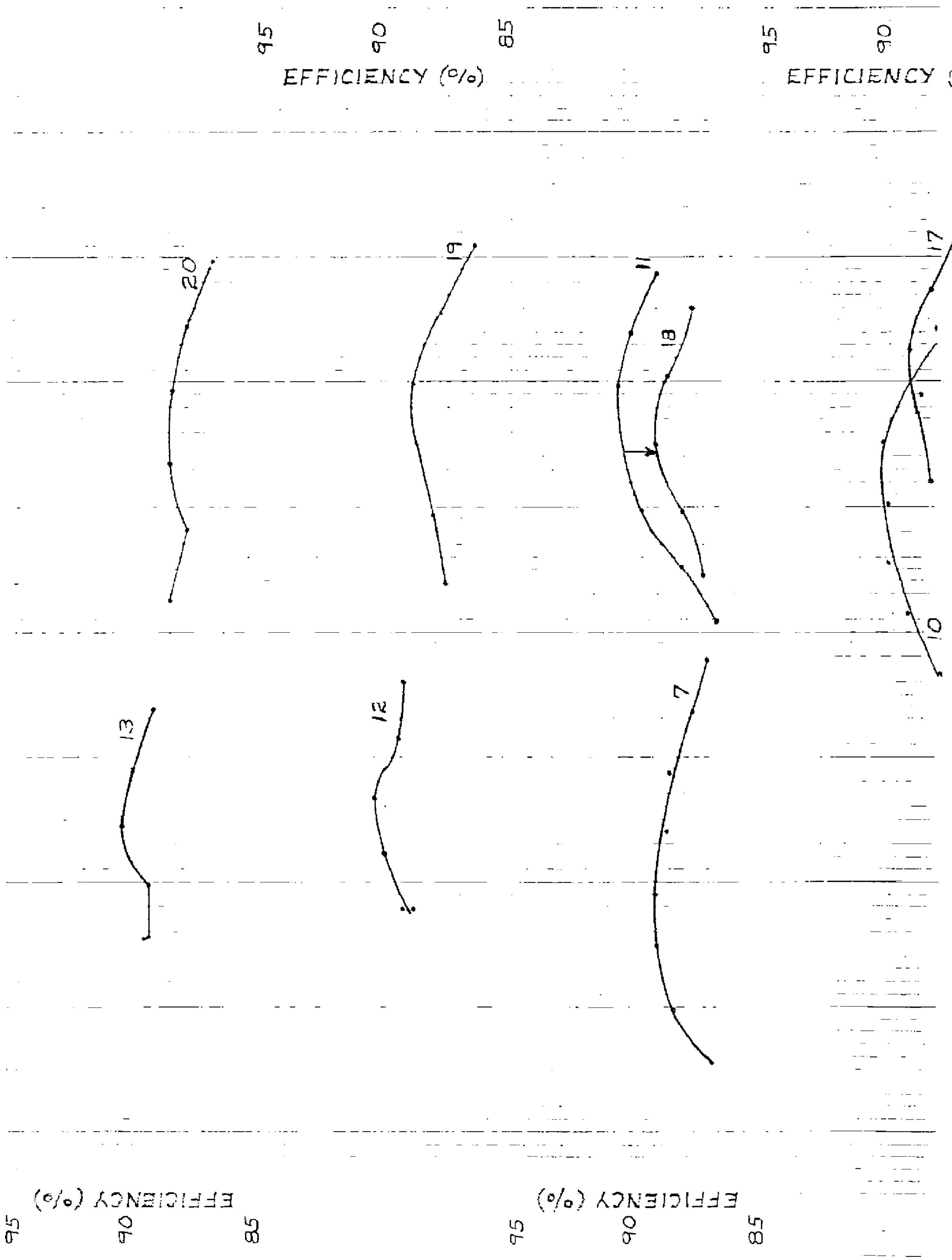
Enclosure

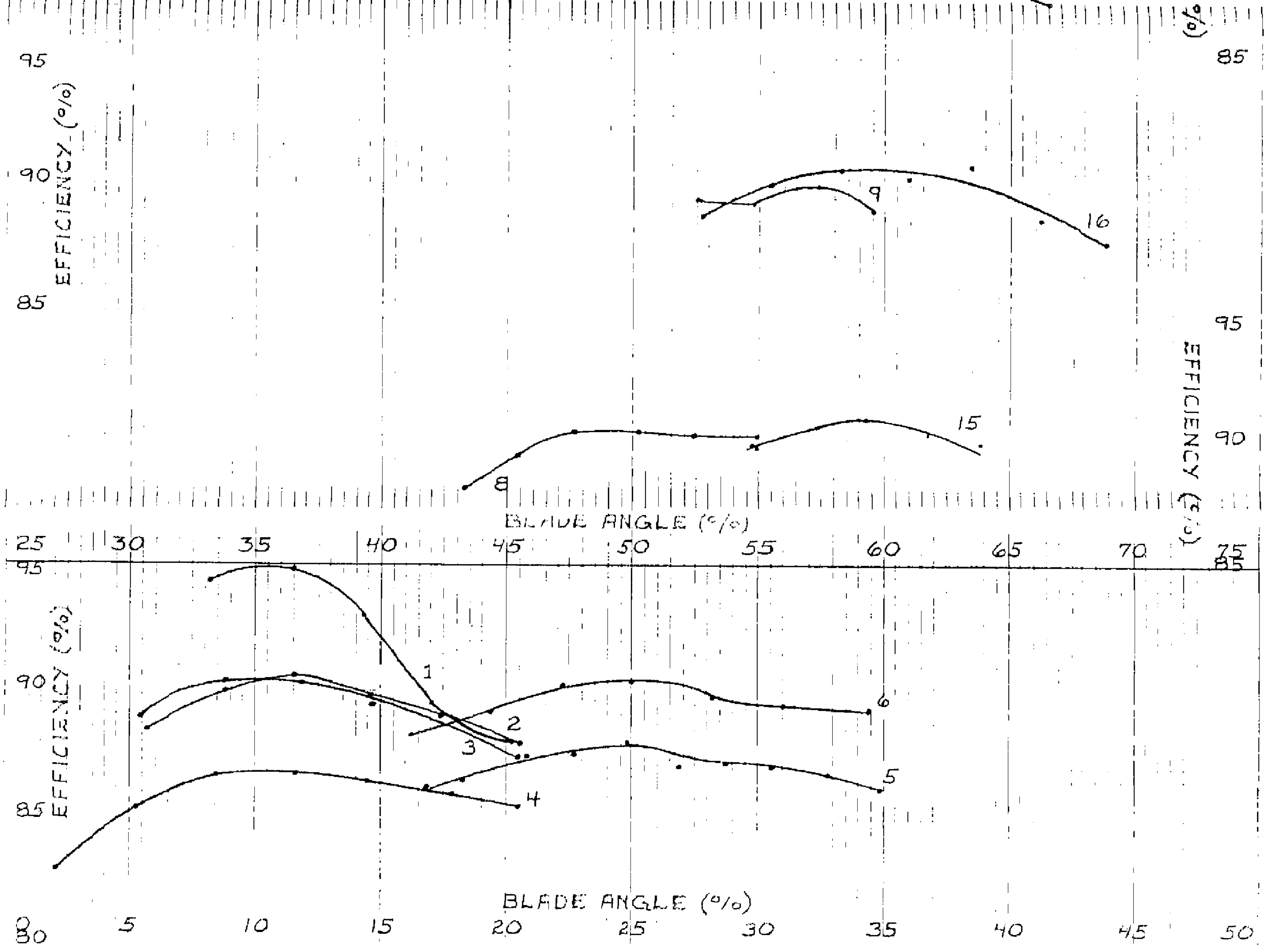


1.5
1.0
0.5
0
EFFICIENCY INCREASE (%)
15
20
25
30
35
POWER (MW)
75
70
65
60
WEIGHTED AVERAGE
55
50
45
40
17
15
16
11
18
20
9
19
10
8
12
13
OPTIMUM CAM CURVE


BLADE ANGLE (°)
30
25
20
15
10
5
30
35
40
45
50
55
60
65
70
75
80
GATE OPENING (%)
CAM CURVE FROM MODEL TEST
● DENOTES PEAK EFFICIENCY
1
2
3
4
5
6
7

GRAPH 1


95
90
85
EFFICIENCY (%)
95
90
EFFICIENCY
20
19
11
18
17
10
13
12
7
EFFICIENCY (%)
95
90
85
EFFICIENCY (%)
95
90
85



EFFICIENCY (%)
95
90
85
EFFICIENCY (%)
85
95
90
16
9
15
8
BLADE ANGLE (%)
25
30
35
40
45
50
55
60
65
70
75
95
85
EFFICIENCY (%)
1
2
3
4
5
6
90
85
80
BLADE ANGLE (%)
5
10
15
20
25
30
35
40
45
50

GRAPH 2