Memo to: Rod Wittinger of USACE
From: Doug Albright of Actuation Test Equipment
Date: January 16, 2006
Subject: ITB December 12-16 Field Test Report

The ITB Field Test was performed on Unit 9 at McNary dam in Umatilla Washington. During this test 155 MB of data was collected. Some said it was "TMFD," but sadly, due to limitations in USACE equipment, after a full analysis it was learned that there is still not "enough data" to properly optimize the turbine. Future testing will not have this problem because the ITB data is viewable as it is collected, so it will be easy to see when enough data has been collected.

The ITB Team agreed in our last Friday meeting that extrapolated data could be used to document the optimization procedure for this report in order to fulfill ATECo's obligation under the contract. It has not been discussed how USACE will fulfill it's obligation to provide ATECo with full and complete operating data for a Kaplan turbine.

The attached graph predicts a new 3-D cam profile, but due to deficient data this is only a "best guess." The desired data set would have bracketed the indicated best cam line by showing an efficiency decrease on both sides of the peak of at least ½ percent.

As shown in the graph, USACE equipment limitations prevented the blades from moving far enough below cam to adequately define the new cam profile with the desired degree of confidence, so only a best guess could be extrapolated from the collected data.

This report described the methods used, the data collected and the problems encountered during the field test.

Test Method
The method used for this test was the Constant Generation Level. The preferred unit configuration for this method utilizes a load-feedback governor system to hold power constant while positioning the blades at different angles, tracing a "constant generation" curve as shown in the accompanying graph (Fig 3) by the blue lines connecting the blade position data points.

Head, Flow and Power data are simultaneously collected to determine operating efficiency at each gate-blade pair operating point along the constant generation lines.

Data Collection
Collected data was filtered using the ITB SteadyState algorithm to remove noisy and transitional data, storing only the steady state values for PostProcessor reduction to prepare the attached graph.

Data was collected in 15-point data bursts. Points in the burst are 1.5 seconds apart. Each point is representative of a "rolling average" output of the SteadyState routine in the ITB. This rolling average is representative of a 3 to 5 minute period, depending on what other ITB features are activated. More screen imaging for data presentation slows data collection due to processor multi-tasking. Longer averaging periods are necessary to filtering out the long time constants of upper and lower pool levels as unit operating levels are changed. In this case, slower is better.

Due to the short test period and our inexperience with the data collection tools, filter limits were set wider to allow a larger amount of data to be collected in the available time. It was felt that more data would be better, which turned out to be true. This provided ample data to develop and demonstrate the PostProcessor tools, and a higher confidence level in the data that was ultimately used to develop the attached graph.

Most of the data was collected at 74 ft head. Some useable data at 73 ft head was collected on the 13th, but is not utilized in this report.

Operating the Unit
For each test point collected during this test, the unit was manipulated manually to place gates and blades at the desired test points by setting the generator load SetPoint slightly above the desired power level, and then bringing the governor's Gate Limit down to hold power at the desired level. After the 30 second delay before the SoftPLC 3-D cam repositioned the blades, the ITB Blade Perturbation output to GDACS was used to re-position the blades to the desired position.

Moving the blades usually affected power level, so another movement of the Gate Limit was made to return to the desired power level. This iterative process was repeated until the desired power level and gate position were obtained for each test point.

Some scatter in power level in the data was unavoidable due to these equipment constraints, causing noticeable distortion of the constant generation lines on the graph.

Despite these problems, the actual and extrapolated data in the graph is satisfactory to demonstrate the cam surface definition procedure.

Some data was taken "on the governor" to demonstrate system dynamics and stability. Though interesting and suitable for further study, this data was rarely steady state enough to be utilized for reduction to optimize the cam surface.

Reducing the Data
The first step in the data reduction is to sort through the data and discard unusable data by viewing it with the ITB PostProcessor. Data sets were discarded for several reasons.

The fundamental criteria for the sorting process were signal noise and motion of the gates and blades during the measurement interval.

To assist in the sorting process, the ITB postprocessor has a StripChart display (Fig 1) to show how the data behaves over time. If the series of values in a data file is not steady state, i.e. the points don't lie along a straight, horizontal line, the unit was not operating steady state and the data is discarded.

Data set #645 (Fig 2) was selected as an example to show how the data sorting process works.

The time interval of this data burst was from 10:25 to 10:33 AM on 15 December. On the data list from the 15th, this burst is identified as 10:25 to 10:33, MW=53.4, WGO=52.4, B<=21.67, Ideal B<=21.71, (I've used the "<" character to indicate "angle.) Perturbation=0.

The data in this set is not entirely coherent, as shown in the stripchart of Fig 1. The vertical migration of the data points indicates that the unit is not SteadyState.

Perturbation amount is indicated by the color of the dot in the center of each blade angle data point on the stripchart. The changing color dot in the center of the blade points at the right side of the StripChart shows that the ITB Perturbation was changed before the end of this data set to intentionally move the blades, so the last 4 points in this data set should be removed from initial consideration of this group. Points collected before these were still steady state. By discarding the last 4 points this data set becomes steady state enough to include in the output graph.

The data points are taken from left to right at a time interval of about 1.5 seconds per point, except for the ones on the right side, which have 20-30 seconds between them. Gaps in the time registry column in the tabular data of Fig 2 show how many data points were discarded in the field by the SteadyState algorithm. Points are collected at a maximum rate of 1 every 1.5 seconds. Time gaps between collected points show that the SteadyState routine in the software does what it's supposed to do.

From the data table; the SteadyState routine rejected data points in between 74 and 75, waiting for the unit to resettle again before capturing points 74 and up as SteadyState points, which is why the vertical differences between the last four points are so large. The data table in Fig 2 and the associated 5Kaverages file show this transaction more clearly.

The StripChart also shows that up until the blades moved, the flow and efficiency values are migrating slowly while the gates and blades were holding steady. This point is not perfectly "SteadyState," but it can still be evaluated to learn something about the unit's efficiency performance and be included in the graph.

Seemingly there are water-column inertia and water level time constants working here that are affecting flow & efficiency while gates & blades are holding steady. Rotor inertia is holding generation level steady over the entire burst time interval. This data indicates the need for long measurement intervals to filter out these effects.

Because the SteadyState routine is presorting this data, we need only determine that the levels of the individual data points are the same before using the data to draw the map. When the ITB is fully functional with the next round of software mods requested by HDC, each data point will stand on its own merit as a SteadyState point. For now, having a cluster of them as we do now allows them to support and encourage each other.
After the sorting, 61 data files were left, each of which becomes one data point on the attached output graph.

This data can be further analyzed using the 5kAverages data set which contains not only this information, but also many prior and following data points; all of the points from within this group that were discarded by the SteadyState algorithm; the raw data points, standard deviations and linear regression slopes that the SteadyState routine used in its analysis are also there.

Presenting the Data

Data produced by this method is evaluated using a 2-dimensional Cartesian coordinate graphing technique similar to the conventional method to derive the new optimum cam profile for head and gate to blade angle.

The constant generation lines sweep from the upper left corner to the lower right corner of the conventional Gate-blade graph, asymptotically approaching the gate and blade axes at the extremities.

By plotting this data on top of the conventional 3-D cam "hill curves" data from the constant generation method, direct comparison and contrast can be drawn against data collected using the conventional "fixed blade, moving gate" turbine testing methods.

Note that the constant generation curves are more vertical at the lower power levels and becoming more horizontal at the higher power levels, and the efficiency performance has the opposite tendency. This plotted relationship shows the natural tendencies of a Kaplan turbine in response to varying unit gate and blade geometries. Using the ITB PostProcessor tools it is a simple matter to identify the impact of a 1-degree deadband in the blade positioning mechanism.

Features of the Graph

Blue curved lines connect the 61 Blade/Gate points, and green lines connect the 61 efficiency points to show the efficiency profile of the unit. From these curves, the optimum Blade to Gate line is drawn as the blade-gate pair associated with the peak efficiency point, illustrated as the heavy violet line across the bottom of the data set.

A single data point on the graph consists of 4 parameters, each plotted against gate position on the graph. These are Gate vs. Blade, Flow, Power and Efficiency.

Data points are color coded to indicate what they are. The blade position points are each black circles with a colored center dot, all points at a common power level are connected by blue curved lines. The color of the center dot indicates the Perturbation value from the ITB to the SoftPLC necessary to get the blades to the measured point. The color code for these center dots is in the vertical reference key at the upper right corner of the graph.

Flow values are indicated by blue dots. Power is red, and Efficiency is green.

Multi colored blade position points are connected to show constant generation by blue curved lines.

Green efficiency points are connected by green lines to show the efficiency contour relative to the blade to gate sweeps at a constant power. Note the connected points for efficiency and blade correspond vertically, showing the interrelationship of these two parameters.

Blade and efficiency points were extrapolated in aqua to guess where they might have gone to demonstrate the cam profile technique.

The vertical green lines are used to connect the extrapolated efficiency crests down to the corresponding extrapolated blade to gate points to delineate the new optimum cam line.

Two black lines drawn parallel to the cam lines indicate ±1 degree3-D cam deadband for reference to show the effect of the 1-degree deadband on blade position and turbine operating efficiency.

The heavy violet line is the new optimum cam line delineated by the efficiency contour data on the graph.

Note this is only a predicted line, projected from the extrapolated gate and efficiency contour lines. A complete data set will be necessary to determine the optimum cam line with any degree of confidence.

Numeric scales for blade angle and percent are on the left side of the graph, flow, power and efficiency values are indicated by numbers embedded in the graph on the right side.

Not Enough Data

Due to the limited authority (±2 degrees) allowed to the ITB by the GDACS 3-D cam programming, and the ±1 degree deadband programmed into the SoftPLC 3-D cam (in addition to the typical hysteresis in a blade controlling mechanism), the ITB's Blade Perturbation could not move the blades far enough below the cam to see the efficiency curves crest over and see two efficiency decreases on either side of the crest.

When the 1-degree deadband was identified, plant personnel were asked, and agreed to tighten this up to .3 degrees. This helped, but did not achieve the desired result; the blade excursion was still insufficient to get enough data on the below-cam side of the new on-cam line identified by the ITB.

Due to the insufficient data available for a high confidence data reduction, HDC agreed to an extrapolation of the available data to demonstrate the reduction technique.

This extrapolation is indicated on the data presentation graph by aqua colored lines added to both blade and efficiency plots that extend the measured blade-gate and computed efficiency lines to show a predicted crest and lead to the indicated optimal cam line.

H74 P56.75 G52.38 B21.32 E86.74 074data12-15-2005 645.prn

LdHd SvHd HdFx Clear

Data	From	McNary	Dam	USACE	82925	Devore	Road	Umatilla	OR	97882	Index	Test	Optimizer	SetUp	and	Data	Entry	Tech	
Screen	WKExp=	.5	WKFactor	=	5818	SpecHead	=	74	Timer=	76707.31									
OPCTa	AIU99FE(	AIU99TE	NET_HEA	GATE_PI	IDEAL_BI	ITB_PERTI	OffsetSiz	AIU99BA	XduHiVo	XduHiEU	XduHiL	FlowCalcIn	OPCTags						
names	Forebay	Tailwate	GrossHea	Gate	IdealBlad	PertOn/Off	BladeOff	Blade	FlowVolts	InchesWC	FtWC	Flow	CorrFlow	Power	CorrPow	RelEfficie	Timer		
TPNum	(Ft)	(Ft)	(Ft)	(%)	(Deg)	(Boolean)	(Deg)	(Deg)	(Volts)	(Inches)	(Feet)	(cfs)	(cfs)	(MW)	(MW)	(%)	(Seconc		
64	339.25	265.38	73.87	52.38	21.71649	1	0.4	21.27	1.3257	34.068	2.839	9802.9	9811.5	53.006	53.146	86.602	37397.3	10:23:17	
65	339.25	265.38	73.87	52.38	21.71649	1	0.4	21.27	1.3255	34.068	2.839	9802.9	9811.5	53.007	53.147	86.603	37398.4	10:23:18	
66	339.25	265.38	73.87	52.38	21.71649	1	0.4	21.27	1.3252	34.056	2.838	9801.2	9809.8	53.006	53.146	86.617	37399.5	10:23:19	
67	339.25	265.38	73.87	52.38	21.71704	1	0.4	21.27	1.3235	34.008	2.834	9794.3	9802.9	53.005	53.145	86.676	37400.7	10:23:20	
68	339.25	265.38	73.87	52.38	21.71704	1	0.4	21.27	1.323	33.996	2.833	9792.6	9801.2	53.005	53.145	86.691	37401.9	10:23:21	
69	339.25	265.38	73.87	52.38	21.71704	1	0.4	21.27	1.3221	33.972	2.831	9789.1	9797.7	53.005	53.145	86.722	37403.0	10:23:23	
70	339.25	265.38	73.87	52.38	21.71704	1	0.4	21.27	1.3213	33.96	2.830	9787.4	9796.0	53.005	53.145	86.737	37404.2	10:23:24	
71	339.25	265.38	73.87	52.38	21.71704	1	0.4	21.27	1.3206	33.936	2.828	9784.0	9792.6	53.006	53.146	86.769	37405.3	10:23:25	
72	339.25	265.38	73.87	52.38	21.71704	1	0.4	21.27	1.321	33.948	2.829	9785.6	9794.2	53.006	53.146	86.755	37406.5	10:23:26	
73	339.25	265.38	73.87	52.38	21.71704	1	0.4	21.27	1.3218	33.972	2.831	9789.1	9797.7	53.007	53.147	86.725	37407.6	10:23:27	
74	339.25	265.38	73.87	52.38	21.71704	1	0.4	21.27	1.3223	33.984	2.832	9790.8	9799.4	53.008	53.148	86.712	37408.8	10:23:28	
75	339.25	265.38	73.87	52.38	21.71704	1	0.4	21.27	1.3222	33.984	2.832	9790.8	9799.4	53.01	53.15	86.715	37410.0	10:23:30	
76	339.25	265.38	73.87	52.38	21.71657	1	0.4	21.27	1.3195	33.912	2.826	9780.5	9789.1	53.011	53.151	86.808	37413.5	10:23:33	
77	339.25	265.39	73.88	52.37	21.71458	0	0	21.67	1.3316	34.224	2.852	9825.4	9834.7	53.391	53.543	87.043	37798.0	10:29:58	
78	339.25	265.38	73.89	52.37	21.71582	0	0	21.67	1.3353	34.332	2.861	9840.9	9849.6	53.397	53.538	86.903	37822.6	10:30:22	

Figure 2 Data Table of one point.

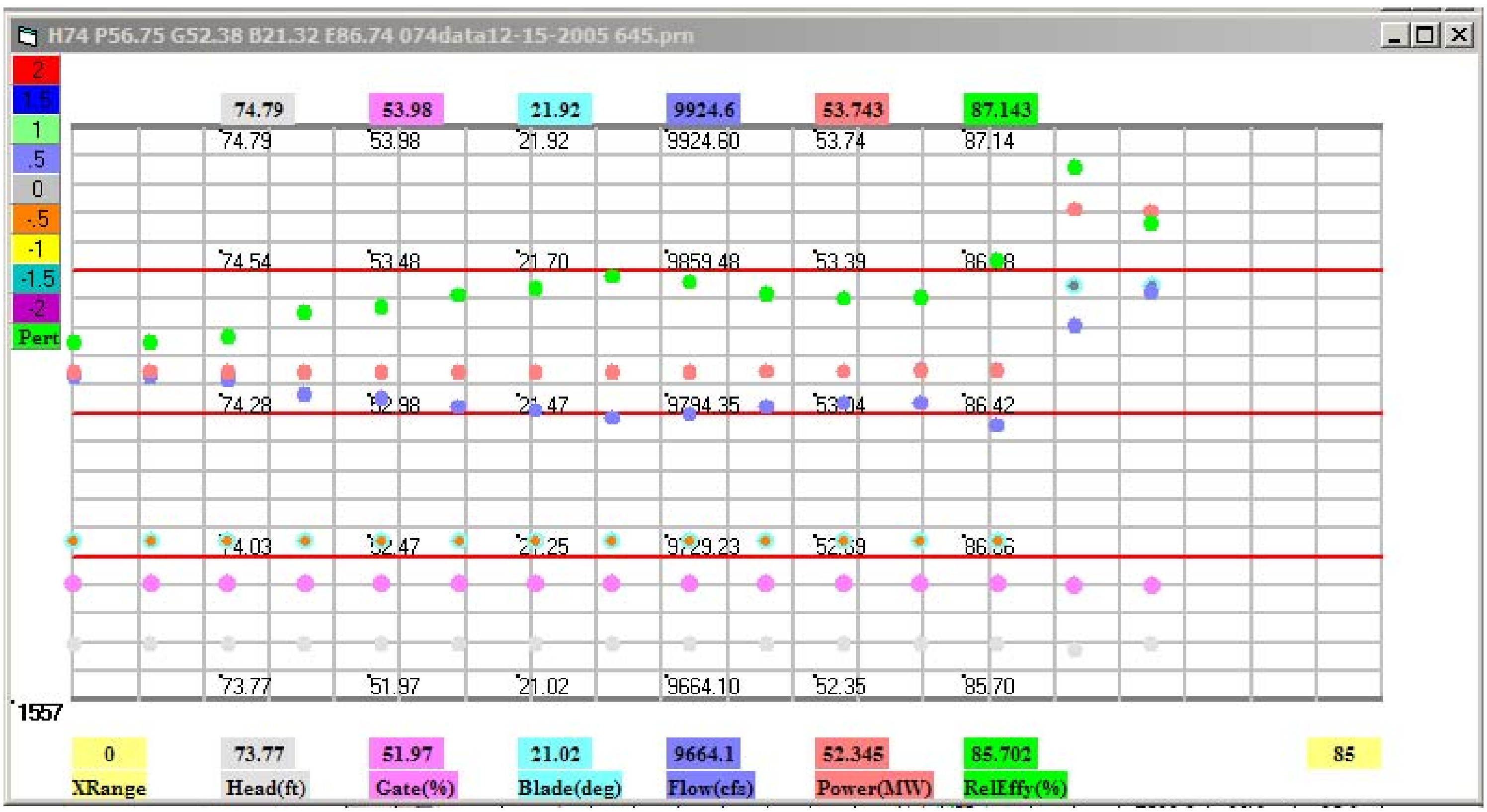
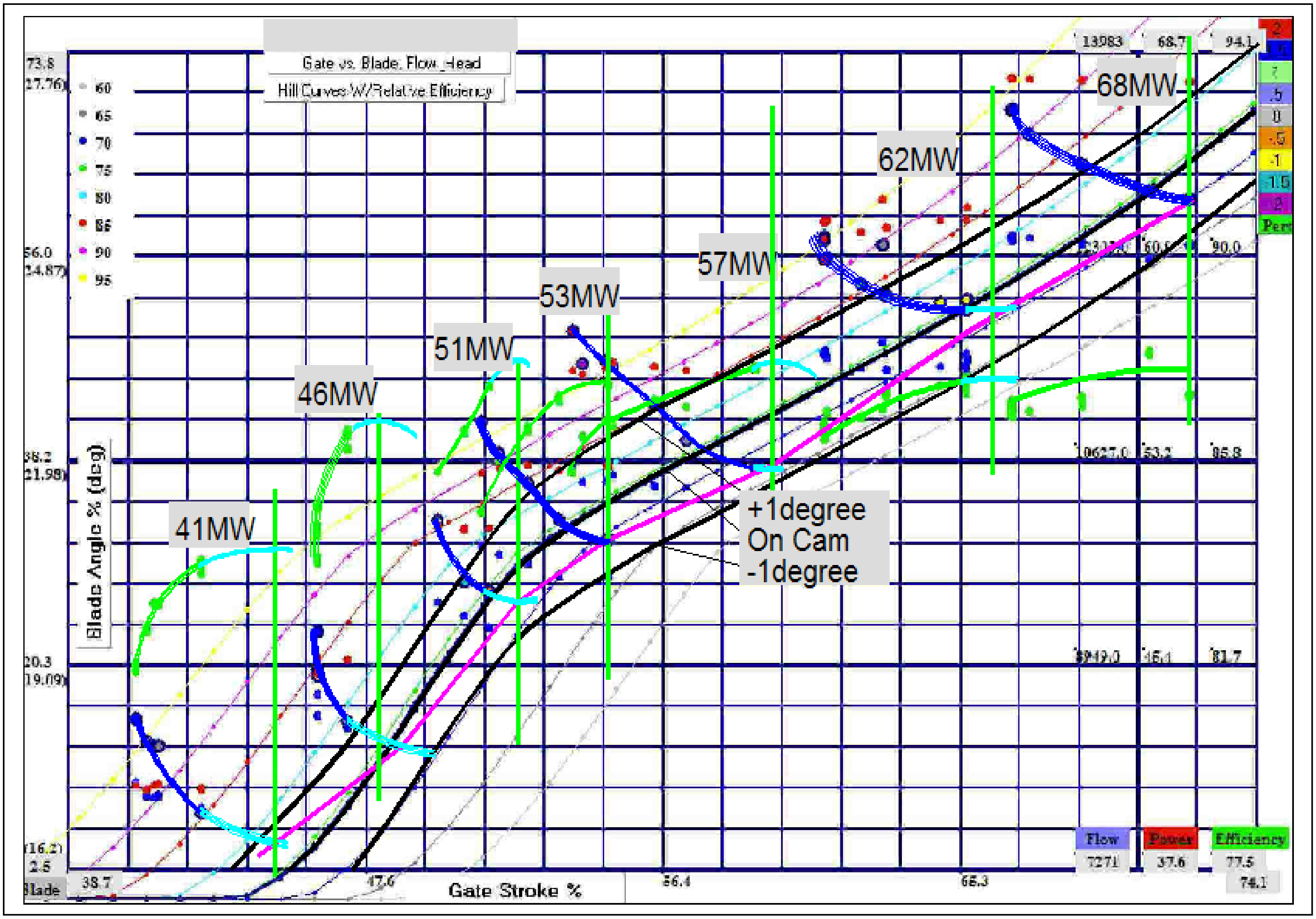


Figure 1 Strip Chart display of data points



Conclusion
At this point in time it is more important to show how the ITB can identify and characterize SteadyState performance than it is to characterize the unit's performance on this specific data run.

This data run is insufficient due to the limited blade excursion caused by the 1-degree (6.5%) deadband in the 3-D cam software, so some extrapolation was required to demonstrate the reduction technique.

We did not take steps to approach each data point from the same direction, so we don't know which way the hysteresis would be loaded for each data point. If the 5kAverages files are always collected, however, this assessment can be made on the data set, providing an even greater degree of confidence in the analysis.

It is my opinion that the ITB has preformed as the USACE desired. Subsequent data reduction and analysis programs are also provided. These have used the collected field data to again demonstrate compliance to produce the graph above.

Best,
Doug Albright