Effect of Butterfly Valve Disc Shape Variations on Torque Requirements for Power Plant Applications

M. S. Kalsi, B. Eldiwany, Vinod Sharma, Aaron Richie
Kalsi Engineering, Inc.

ABSTRACT

Tests performed by the U.S. NRC/INEL under the "Containment Purge and Vent Valve Test Program" in 1985 showed that manufacturers methods for predicting torque requirements had serious limitations. Under design basis conditions, torque requirements in single-offset valves with shaft downstream were found to be self-opening, instead of self-closing as predicted by valve manufacturers. It was also found that variations in butterfly disc shapes are quite large and the influence of disc shape, upstream piping configuration, ΔP and unchoked vs. choked flow conditions on torque requirements in compressible and incompressible flows had not been adequately addressed by the industry. EPRI, under its MOV Performance Prediction Program (1990-1994), developed analytical models and conducted tests to address some of these shortcomings. However, the models were based on simple analytical approaches with large conservatism to cover known uncertainties, and testing was limited to incompressible flow with only symmetrical and single-offset disc geometries. Furthermore, the EPRI methodology was developed for MOVs, which have a constant actuator output torque capability, and therefore, did require position dependent accuracy in torque predictions for margin evaluation. Torque prediction methodologies for AOVs need to have position dependent accuracy because AOV actuator output varies with stroke. Consequently, the MOV methodologies are generally not suitable for accurate assessment of AOV margins.

This paper presents highlights of a comprehensive and advanced butterfly valve model development program that overcomes above limitations. Incompressible and compressible flow test programs have been described in earlier papers. The focus of this paper is to present the key results from analytical research and testing that overcome limitations that were identified in earlier programs. The disc shape and certain key geometric features that influence the valve performance are discussed. This paper also provides examples of the advanced models and the benefits derived from the efficient use of the massive database of flow and torque coefficients by a software to address design basis evaluations for both incompressible and compressible flow plant applications.

INTRODUCTION

To meet an important industry need for evaluating the capability of safety-related Air-Operated Valves (AOVs) to operate under design basis conditions, Kalsi Engineering, Inc. initiated a comprehensive program to develop validated models for quarter-turn valves. The program included development of first principle models, extensive computational fluid dynamics (CFD) analyses, and flow loop tests (incompressible and compressible flows) on all common types of AOV quarter-turn valves. The test program included systematic evaluation of a wide matrix of disc shapes, elbow orientations and proximities, and pressure drop ratios/flow rates on the required torque. The program was conducted under a quality assurance program that meets 10CFR50 Appendix B requirements. Earlier papers [1, 2][*] provide and overview of the incompressible and compressible flow test programs. The products of this program are advanced, validated models and software (KVAP™) for AOV/MOV design basis sizing and margin calculations [13].

The new models and KVAP software have significantly advanced the state-of-the-art and provide the most comprehensive database in the industry for accurately predicting performance of all common types of quarter-turn and linear valves. This paper presents an overview of the previous industry developments relevant to this program, provides a discussion of key results/insights and summarizes plant experience and the benefits achieved by the utilities from application of these new models at many nuclear power plants.

LIMITATIONS OF EARLIER BUTTERFLY VALVE PROGRAMS

NRC/INEL Containment Purge and Vent Valve Test Program

A survey performed by NRC/INEL [5] showed that valve manufacturers did not have validated methodologies for reliable torque predictions of butterfly valves that appropriately take into account the variations in disc geometry as a function of valve size, pressure class, model; fluid media (compressible or incompressible); pressure drop ratios and flow rates from fully choked to unchoked/low ΔP conditions. Many manufacturers had performed tests on a few small valves (usually 8" or smaller) and developed sizing predictions for their entire product line without considering the geometric deviations with valve size/pressure class and validating the predictions against large valve tests. Compressible flow tests were generally performed under low flow/low ΔP unchoked conditions across the valve; the performance under choked flow conditions had not been properly addressed. The effect of different elbow configurations and their proximities on torque requirements had also not been evaluated by most manufacturers.

Under the “Containment Purge and Vent Valve Test Program,” U.S. NRC/INEL performed tests on three butterfly valves (two 8” and one 24” valves from two manufacturers) with gaseous nitrogen under blowdown conditions [4, 5]. Testing was limited to single-offset disc design (Figure 1), because the NRC survey showed that this design had the dominant population in the U.S. nuclear power plants. The program included testing with upstream elbows at valve inlet with four different configurations.

---

[*] Numerals in brackets denote references listed at the end of this paper.

One of the most surprising test results found by NRC/INEL was that under design basis conditions, the valve performance with shaft downstream orientation was totally opposite of manufacturers' predictions (self-opening throughout the stroke instead of self-closing over majority of the stroke).

The program did not include symmetric disc, double- and triple-offset disc designs, even though the population of double-offset disc designs in containment purge applications is relatively significant. Furthermore, tests on two valves in series (typical installation in containment purge applications) were not included. Most of the tests were performed under choked flow conditions, and only a few of tests under low ΔP, unchoked, flow conditions were performed. NRC/INEL provided recommendations to the industry for further testing to overcome these limitations.

EPRI MOV Performance Prediction Program (PPP)

EPRI MOV PPP was a comprehensive program to develop performance prediction models for gate, globe and butterfly valves. The program included incompressible flow testing on symmetric and single-offset disc designs of different aspect ratios [6, 7, 8]. The EPRI program objective was to develop a methodology for MOV applications. For MOV evaluations, only a *single value* for the *peak required torque* is needed, regardless of where the peak occurs (Figure 4A). Therefore, the analytical model development of EPRI MOV PPM did not require position-dependent accuracy in torque predictions. The analytical models that form the basis of EPRI MOV PPM symmetric and single-offset butterfly valve methodology were based on simplified, thin disc 2D streamline analysis approximations. Adjustments to torque coefficients to take into account disc thickness (aspect ratio) and shape were based upon simple hydraulic resistance calculations, available industry data and engineering judgment. Relatively large margins had to be included in these approximate models to cover uncertainties, simplifying assumptions and the limitations of the then available test data [6, 7].

Validation of the EPRI MOV PPM models against flow loop and in-situ test data showed that even though the *Required Torque* predictions bounded the EPRI test data [7, 8], the dynamic torque signature predictions lacked position dependent accuracy required for AOVs as shown in Figure 4B. The total required dynamic torque predictions as a function of disc position (also referred to as *Torque Signature Predictions)* were in some cases overly conservative, and in other cases nonconservative over large portions of the stroke, e.g., as shown in Figures 2 and 3. EPRI issued information notices, error notices and industry guidance to address potential known nonconservatism of EPRI MOV PPM predictions while evaluating AOVs [10, 11, 12].

KALSI ENGINEERING, INC.'S ADVANCED MODEL DEVELOPMENT PROGRAM FOR AOVS/MOVS

To develop validated models with position-dependent accuracy for all common types of quarter-turn valves in nuclear power plants, and to overcome the limitations of the NRC/INEL "Containment Purge and Vent Program" and the EPRI MOV PPM discussed above, Kalsi Engineering conducted a comprehensive development program that included advanced analytical modeling, compressible and incompressible flow testing, The program spanned over three years and was conducted in two phases: Phase I focused on incompressible flow applications including analytical model development, flow loop testing, and validation. Under Phase II, advanced compressible flow models were developed based upon Computational Fluid Dynamics (CFD) analyses and compressible flow testing covering a wide range of pressure drop ratios from highly choked to unchoked conditions. The disc shape test matrix and highlights of the program results are presented below.

Matrix of Disc Shape Geometries

Surveys by NRC/INEL and EPRI/NMAC show that the following basic butterfly valve disc types are commonly used in the industry:

- Symmetric Disc Butterfly
- Single-Offset Butterfly
- Double-Offset Butterfly
- Triple-Offset Butterfly

In addition to butterfly valves, Kalsi Engineering recent survey from twenty nuclear plants showed that the following types of quarter-turn valves are also common in AOV applications:

- Spherical Ball
- Segmented (V-Notch) Ball
- Eccentric Plug
- Cylindrical/Tapered Plug

The advanced model development program performed by Kalsi Engineering covered both butterfly and other types of quarter-turn valves. Figures 5-9 show the geometry, relative proportions and key features for various types of butterfly valves that were tested. To adequately cover the variations in disc geometries common in nuclear power plant applications, a total of 25 disc shapes were included in the test matrix. In addition to systematically covering variations in the disc aspect ratio, the matrix also included scale models of disc geometries having exact geometrical similarities to the 18”, 36”, 42” and 48” valves used in safety related nuclear plant applications. The scale model testing approach was used because this approach was validated against 42” full-scale valve test data under the EPRI MOV PPP.

The butterfly valve disc shape variations included in the test program are described below:

Basic disc types:	Symmetric & non-symmetric (single-offset, double-offset and triple-offset designs).
Disc aspect ratio:	0.15 to 0.31 for symmetric disc designs 0.09 to 0.47 for non-symmetric designs

Disc front face geometry: Flat or recessed. The recess can be flat or concave (Figures 6, 7). The non-flat, recessed front face geometries are common in cast designs.

Disc shaft side geometry: Prismatic, conical or radiused. This disc face can be relatively smooth (e.g., prismatic shapes typically fabricated from plate/machined components) or have bosses/projections and recesses (which are common in cast designs). Another variation in the shaft side disc faces included stub shaft hub design. Figures 6 and 7 show these geometric variations.

It should be noted that all tests on single-offset butterfly valves performed by NRC/INEL and EPRI MOV PPP used disc geometries, which had flat front faces as shown in Figure 1. The non-flat face geometries can have higher torque requirements than flat face geometries as will be discussed under Key Results.

Matrix of Incompressible & Compressible Flow Tests

Both incompressible and compressible flow tests were performed with baseline configuration (no upstream elbows within 20 pipe diameters) and with various elbow configurations and proximities (from 0 to 8D) as described in References 1 & 2. The test sequence for each valve installation/configuration typically consisted of 17 static/dynamic strokes for incompressible flow testing, and up to 24 strokes for compressible flow testing. This resulted in a total matrix of 1,272 tests for incompressible flow and 1,116 tests for compressible flow. The flow loop testing provided a massive database of nondimensional hydrodynamic torque/flow coefficients (for incompressible flow) and aerodynamic torque coefficients (for compressible flow) for various valve geometries over a range of wide flow conditions.

KVAP SOFTWARE*: The tool for efficient and user-friendly application of advanced models and massive database for complete AOV/MOV evaluations*.

The calculations necessary to predict torque requirements for quarter-turn valves are very extensive, time consuming and potentially error prone because they require a detailed knowledge of the methodologies, and a large number of parameters, which are application specific. This dictated the need for development of a software to help utility engineers perform calculations efficiently without being burdened with extensive interpolations required to account for: (a) application specific torque/flow coefficients which depend upon valve geometry (disc shape, aspect ratio), (b) installation parameters (disc orientation, elbow configuration/proximity), and (c) operating conditions (pressure, $\Delta P/P_{up}$ ratios, fluid media and flow rate). The advanced validated models as well as the massive database of torque and flow coefficients from the test program were incorporated into a PC based software called KVAP (Kalsi Valve and Actuator Program). The software was developed with emphasis on very intuitive and user-friendly graphical features. Table 1 provides a comparison of validated models that were developed under this program and incorporated in KVAP software against the previously available industry methodologies/software.

In addition to addressing quarter-turn valves, KVAP software includes all linear valves (gate, globe and diaphragm) as well as all commonly used AOV and MOV actuators. In summary KVAP is designed to provide complete design basis evaluations and margins for all AOVs and MOVs in power plants [13].

QUALITY ASSURANCE

All testing, model development, and KVAP software development activities were conducted in accordance with our quality assurance program, which satisfies 10CFR50 Appendix B requirements.

DISCUSSION OF KEY RESULTS FROM ANALYSES & TESTING

Key Results From CFD Analyses

CFD analytical results (including pressure and velocity contours; shock wave location, strength and movement; and interaction between two valves in series) provided insights that were significant in understanding the behavior of butterfly valves in compressible flow. Figure 10 shows a comparison of the Mach number, pressure and velocity distribution for a symmetric disc butterfly valve operating under unchoked, relatively low $\Delta P/P_{up}$ conditions (left picture) against fully choked, high $\Delta P/P_{up}$ conditions (right picture). Under low $\Delta P/P_{up}$ operation, the flow becomes sonic just downstream of the leading edge, and it remains separated from the downstream disc face. However, under choked flow conditions, the flow shock front reattaches itself to the downstream disc face, as shown in Figure 10. The reattachment of the shock front to the disc downstream face causes a jump in the pressure distribution, which in turn dramatically affects the magnitude as well as the direction of the resultant aerodynamic torque on the disc. Furthermore, the reattached shock front changes its location on the downstream disc face as the $\Delta P/P_{up}$ ratio is changed. This explains the non-linear changes in aerodynamic torque as $\Delta P/P_{up}$ ratio is increased from low (nearly incompressible, unchoked conditions) to high (fully choked conditions).

The phenomenon described here is equally applicable to single- and double-offset disc designs with shaft downstream orientations, and it explains why the manufacturers predictions (based upon unchoked, low ΔP tests) were contradictory to the NRC/INEL test under high ΔP, choked flow conditions. This is further discussed under "Key Results from Incompressible and Compressible Flow Testing" section in this paper.

The CFD analyses also showed that the presence of a downstream butterfly valve (Figure 11) can dramatically alter the pressure distribution and aerodynamic torque experienced by the upstream valve. This is due to the fact that the reduction in the flow area at the downstream valve location causes the flow to accelerate, which can cause the shock front to move from the upstream valve to the downstream valve location.

The significant insights obtained from the CFD analyses research provided excellent guidance for the key parameters to be varied in the test matrix for compressible flow testing. The test program covers a wide range of $\Delta P/P_{up}$ ratios from nearly incompressible, low ΔP conditions to highly choked flow conditions. The effect of various upstream and downstream resistances was also systematically evaluated to determine their effect on torque coefficients, as discussed in Reference 2.

Key Results from Incompressible and Compressible Flow Testing

Some of the key results for the incompressible and compressible flow testing that are discussed in this section are shown in Figures 12-15.

Validated Model for Double-Offset Disc Designs

Tests revealed that variations in hydrodynamic torque for double-offset valves (which were not included in the EPRI MOV PPP) can be significant based upon the combination of the first and second offset magnitude, as well as critical disc geometry features, e.g., a concave or recessed disc face instead of a flat face (Figure 12). The sensitivity of the torque coefficients and flow coefficients to streamlining the disc faces as shown in Figure 8 was also evaluated to provide bounding coefficients for the advanced models and KVAP software.

Aerodynamic Torque can Change From Self-Closing to Self-Opening with Changes in $\Delta P/P_{up}$ Ratio

Figure 13 shows that incompressible-flow torque coefficients are independent of pressure drop. Therefore, the hydrodynamic torque magnitude is linearly proportional to ΔP and torque behavior at a given stroke position does not change (e.g., from self-closing to self-opening).

A comparison against the torque coefficients from compressible flow (Figure 14) shows that under low $\Delta P/P_{up}$ ratios, the behavior of the butterfly valve is basically the same as that under incompressible flow testing. Figure 14 also shows that aerodynamic torque for a single-offset disc, with shaft downstream, changes from *self-closing* (under low $\Delta P/P_{up}$, unchoked, nearly incompressible conditions) to *self-opening* as $\Delta P/P_{up}$ is increased to fully choked conditions. This is caused by the reattachment and movement of the shock front on the downstream disc face as discussed above under Key Results from CFD.

Geometry of Downstream Resistance can Provide Significant Relief in Aerodynamic Torque

Figure 15 shows that the geometry of the downstream resistance can have a profound effect on the torque requirements of butterfly valves. The comparison shows that the presence of a fully open downstream butterfly valve significantly lowers the aerodynamic torque of the upstream butterfly valve. An equivalent length of downstream pipe that has the same flow resistance as that of a fully open butterfly valve has a much smaller influence on the aerodynamic torque requirement of the upstream valve. Therefore, for appropriate application, a significant improvement in margin can be achieved by taking credit for this phenomenon. This is particularly important for containment purge valves that are installed in series (typically one valve inside and one valve outside the containment).

Advanced Models Account for Inaccuracies in Torque vs. Position Caused by Upstream Elbows

The presence of upstream flow disturbance (e.g., an elbow) near the inlet of butterfly valves (which is common practice in power plants applications) affects both the magnitude and distribution of the hydrodynamic torque, Thyd. A simple multiplier (like the one provided by the Upstream Elbow Model in EPRI's MPV PPM) cannot account for the shift in Thyd. Advanced modeling is necessary to maintain position dependent accuracy with the presence of upstream elbows.

For example, in a symmetric disc installation without upstream elbow, the hydrodynamic torque component at the fully open position is nearly zero because the flow around the disc is balanced. Upstream elbow installation near the valve inlet skews the flow velocity and pressure distribution around the disc even in the fully open position. This skew in flow velocity and pressure caused by the elbow results in a net positive or negative hydrodynamic torque in the fully open position. The magnitude and direction of the net Thyd depend on the relative orientation and proximity of the elbow with respect to the valve disc. The necessary development and validation for both compressible and incompressible flows have been incorporated in KVAP.

Recessed Faced Discs Exhibit Higher Torque than Flat Faced Discs

Testing with shaft downstream valve orientations showed that discs with recessed flat faces (Figure 7) exhibit higher Thyd than discs with true flat faces without a recess or a depression on the flat face (Figures 1 and 6) especially at the large disc opening angles. The increase in the magnitude of Thyd depends on the depth and extent of these flat face depressions. The advanced methodologies in KVAP account for the effects of typical depressions on torque requirements.

These tests results may show that earlier methodologies are not as conservative as they were considered prior to this test program. The reason is that flow loop testing (prior to KEI testing) was limited to discs with purely flat faces.

APPLICATION EXAMPLES, PLANT EXPERIENCE AND BENEFITS

Since the first release of the KVAP program in November of 2000, the software has been used for AOV and MOV evaluations at a large number of nuclear power plants. In many plants, substantial cost savings (often in excess of $500,000 at each plant) have been realized by the utilities by avoiding the need for modifications due to "apparent" negative margins predicted by other methodologies/software. The following examples show typical improvement in margins based upon the use of the more accurate models in KVAP for incompressible and compressible flow applications. In many instances, modifications of AOV groups containing multiple valves (up to eight in several cases) were proven unnecessary and successfully avoided. Such unnecessary modifications to increase the actuator output torque capability would also require re-evaluation of the AOV weak link and seismic re-qualification of the valve/actuator assembly.

Another significant cost benefit provided by the validated models incorporated in KVAP is that they provide an alternative to dynamic ΔP testing to evaluate the AOV/MOV capability to operate under design basis conditions.

Plant Example 1: Margin evaluation of AOV application highlights misconception. Figure 16 shows a typical input screen and the margin plot from KVAP analysis of an AOV from an actual plant evaluation of a symmetric disc butterfly valve with a Scotch Yoke actuator used in an incompressible flow application. In this application, the minimum AOV margin is dictated by the dynamic torque at around the 25-degree location and not by the unseating torque (at closed position), which is significantly higher. The unseating torque would govern the margin for an MOV where actuator output is constant throughout the stroke. This example shows the importance of position-dependent accuracy in torque prediction models.

An important *general* observation from this plant example is that even though seating/unseating torque may be the highest torque throughout the stroke; this may not dictate the minimum margin in an AOV (unlike in an MOV).

Plant Example 2: Identification of "apparent" negative margin eliminates need for unnecessary modifications. This plant had performed design basis calculations for the six service water butterfly valves operated by piston actuators with lever-and-link mechanism for quarter-turn operation. These AOVs had a maximum disc-opening angle of 60°. Based upon earlier industry methodologies, it was concluded that this AOV had a negative margin under design basis calculations (Figure 17). Modifications were planned to change the actuators to provide higher torque outputs to meet the requirements indicated by the previous analysis. Re-evaluation (using the more accurate validated models described in this paper) showed a positive margin was actually available throughout the stroke. This eliminated the need for changing actuators, resulting in significant cost savings without compromising safety/reliability of valve operation.

Plant Example 3: KVAP application improves margin in containment purge application. Figure 18 shows the comparison of required torque predictions for an 18" double-offset disc containment purge valve (with shaft downstream orientation), to close under design basis LOCA conditions. The AOV actuator was a Scotch-Yoke type with spring return to fail close the valve. The minimum actuator output available from the actuator at various stroke positions had been provided by the manufacturer and verified by the plant engineers. EPRI MOV PPM software indicated a large negative margin throughout the stroke. The use of KVAP software, along with the use of torque/flow coefficients database based upon the appropriate $\Delta P/P_{up}$ ratio for this application resulted in a significant reduction in torque requirements, and a positive margin throughout the stroke. This eliminated the need for plant modifications that were being planned for 8 valves in this group of Category 1 AOVs.

CONCLUSION

The advanced, validated models and KVAP software successfully fulfills the industry need for reliable position-dependent torque predictions for AOVs. The benefits in margin improvement from KVAP are also applicable to MOV applications. Validated models provide an alternative to ΔP testing. Plant experience has shown significant cost savings by avoiding equipment modifications in many applications. KVAP margin improvements may be used to ease plant equipment modification and maintenance burdens by enlarging AOV and MOV actuator field set-up windows, extend periodic verification inspection and test intervals, and improve power uprate and life extension decisions. KVAP software is an efficient, intuitive, and user friendly software developed under our 10CFR50 Appendix B QA program to provide reliable predictions for safety-related applications.

ACKNOWLEDGEMENTS

Kalsi Engineering and the authors acknowledge contributions made by the valve manufacturers, NRC/INEL, EPRI/NMAC, and power plant engineers over the years which led to improved understanding and development of advanced models described in this paper.

REFERENCES

1. “Dynamic Torque Models for Quarter-Turn Air-Operated Valves,” M. S. Kalsi, B. Eldiwany, V. Sharma, D. Somogyi, NUREG/CR-0152, Vol. 3, Presented at The 6th NRC/ASME Symposium on Valve & Pump Testing, Washington, DC, July 2000.
2. "Butterfly Valve Model Improvements Based on Compressible Flow Testing Benefit Industry AOV Programs," M. S. Kalsi, B. H. Eldiwany, V. Sharma, 7th NRC/ASME Symposium on Valve and Pump Testing, Washington DC, Jul 2002.
3. NRC Regulatory Issue Summary (RIS) 2000-03; Resolutions of Generic Safety Issue 158: Performance of Safety-Related *Power-Operated Valves* under Design Basis Conditions.
4. R. Steele and J. C. Watkins. **Containment Purge and Vent Valve Test Program Final Report**, U. S. Nuclear Regulatory Commission, NUREG/CR-4141, Oct 1985.
5. J. C. Watkins, R. Steele, R. C. Hill, and K. G. Dewall. **A Study of Typical Nuclear Containment Purge Valves in an Accident Environment**, U. S. Nuclear Regulatory Commission, NUREG/CR-4648, Aug 1986.
6. “Application Guide for Motor-Operated Valves in Nuclear Power Plants, Volume 2: Butterfly Valves” Prepared by Kalsi Engineering, Inc., TR-106563-V2, EPRI, Palo Alto, CA, Oct 1998.
7. “EPRI MOV Performance Prediction Program: Butterfly Valve Model Description Report,” EPRI TR-103224, EPRI, Palo Alto, CA, Sep 1994.
8. "EPRI MOV Performance Prediction Methodology Assessment Report," EPRI TR-103231, EPRI, Palo Alto, CA, Nov 1994.
9. “Air-Operated Valve Evaluation Guide,” TR-107322, Electric Power Research Institute, Palo Alto, CA, May 1999.
10. “PPM Software Information Notice 2002-1 (Prediction of Butterfly Valve Design Basis Required Torque as a Function of Disk Position)”, EPRI, Palo Alto, CA, May 2002.
11. “PPM Software Error Notice 2003-2 (Required Adjustments to Butterfly Valve Disc Angle Dependent Torque Predictions)”, EPRI, Palo Alto, CA, December 2003.
12. EPRI “Assessment and Recommendations for Using EPRI MOV PPM Butterfly Model for Applications with Variable Actuator Output Torque Capability,” EPRI – 1009227, EPRI, Palo Alto, CA, February 2004.
13. "KVAP User's Manual," Document No. 2099C, Kalsi Engineering, Inc. Sugar Land, TX, Jan 2003.

	Valve Types Prevalent in AOV Population	NRC/INEL Cont. Purge	EPRI MOV PPM (Note 1)	Ace, AirBase, Others (Note 2)	KVAP Software
1	Symmetric Butterfly	None	√*	None	√
2	Single-Offset Butterfly	√**	√	None	√
3	Double-Offset Butterfly	None	None	None	√
4	Segmented V-Ball	None	None	None	√
5	Spherical Ball	None	None	None	√
6	Eccentric Plug	None	None	None	√
7	Tapered/Cylinder Plug	None	None	None	√

*** Incompressible Flow Only**
**** Compressible Flow Only**

General Note: NRC/INEL and EPRI MOV PPP methodologies for single-offset discs were based upon tests performed on discs having flat front faces (no recesses) that may not bound data for recessed designs. Recessed faces are common in cast disc designs.

Note 1: EPRI MOV PPM models provide bounding predictions for MOVs. EPRI Torque Signature predictions can be nonconservative over portions of the stroke. See EPRI MOV PPP Software Information and Error Notices [10, 11, 12].

Note 2: ACE, AirBase, and other software, e.g., Excel spreadsheet, do not have built-in validated torque/ flow coefficients. Predictions based on the use of EPRI MOV PPM coefficients in these softwares can be nonconservative over portions of the stroke. See EPRI MOV PPP Software Information and Error Notices [10, 11, 12].

Table 1

Comparison of Validated Methodologies Available in KVAP Against Other Methodologies/Software

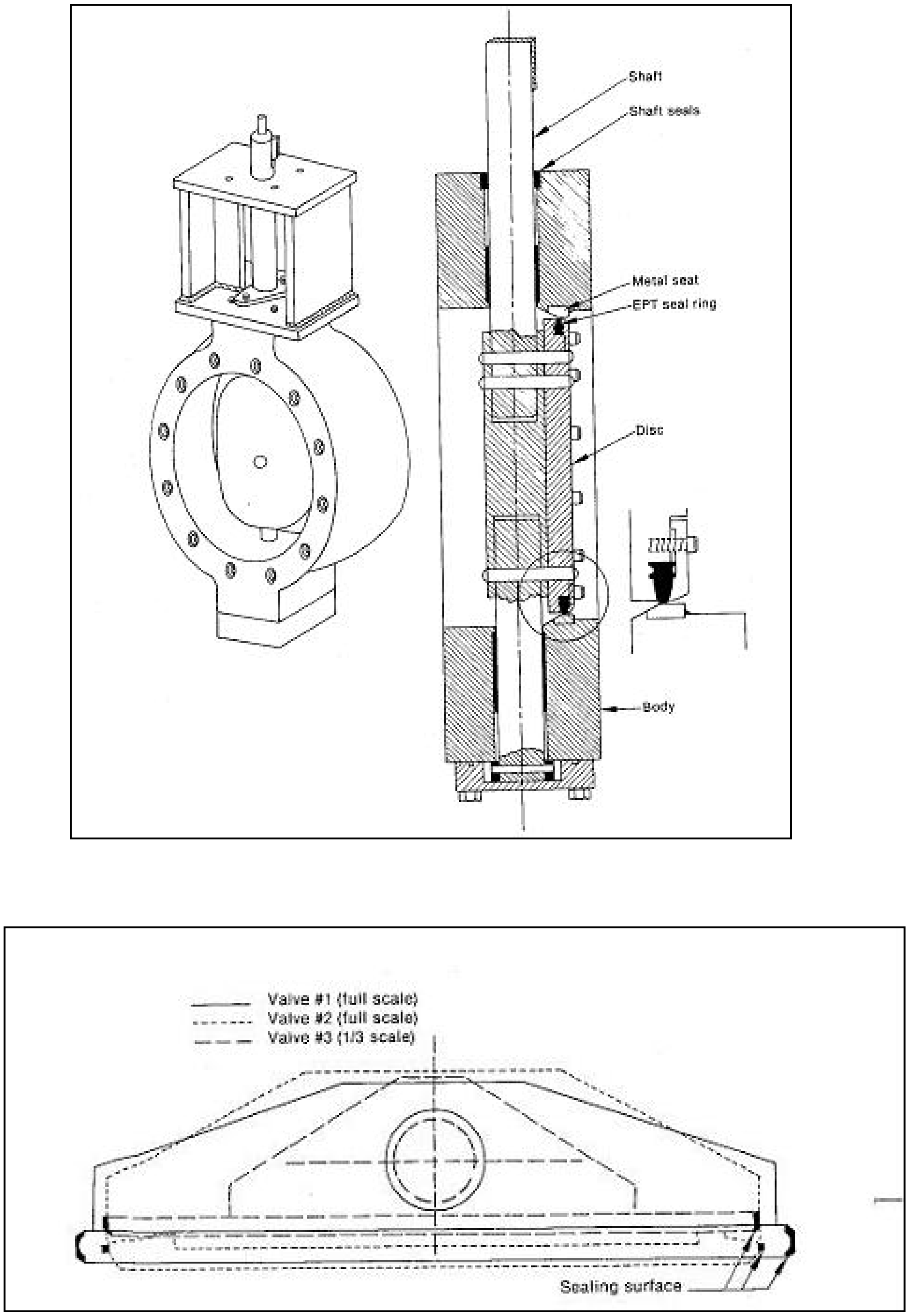


Figure 1: Details of a single-offset butterfly valve (top) and a composite drawing (bottom) showing geometric comparison of disc cross-sections of 3 different disc shapes from 2 manufacturers tested by NRC/INEL [4, 5].

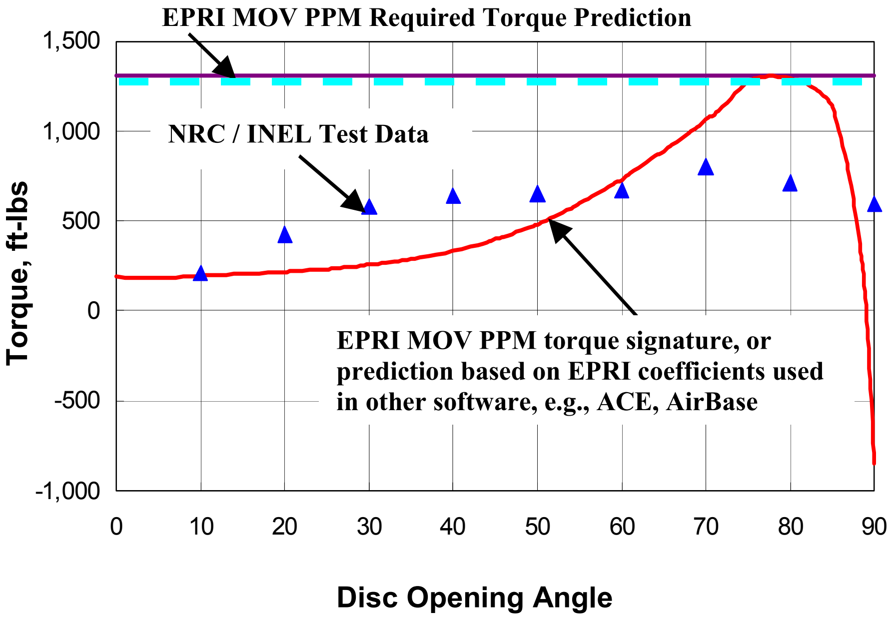
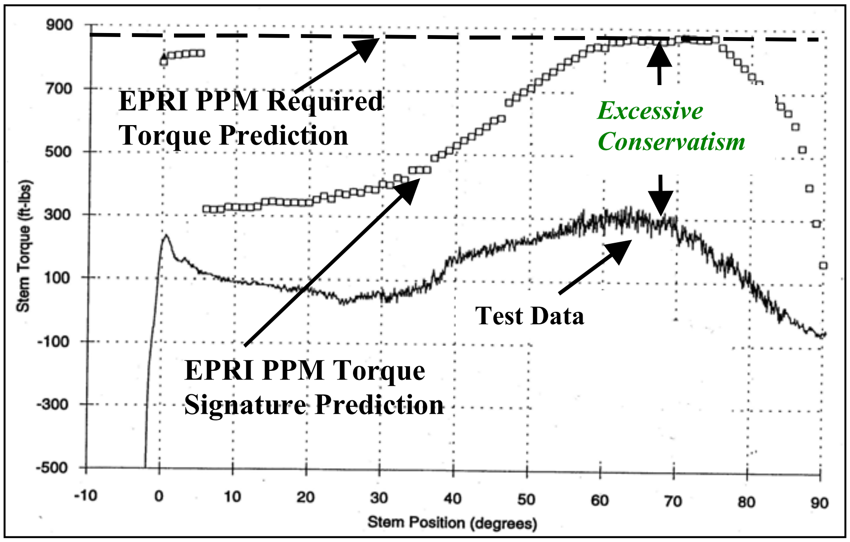
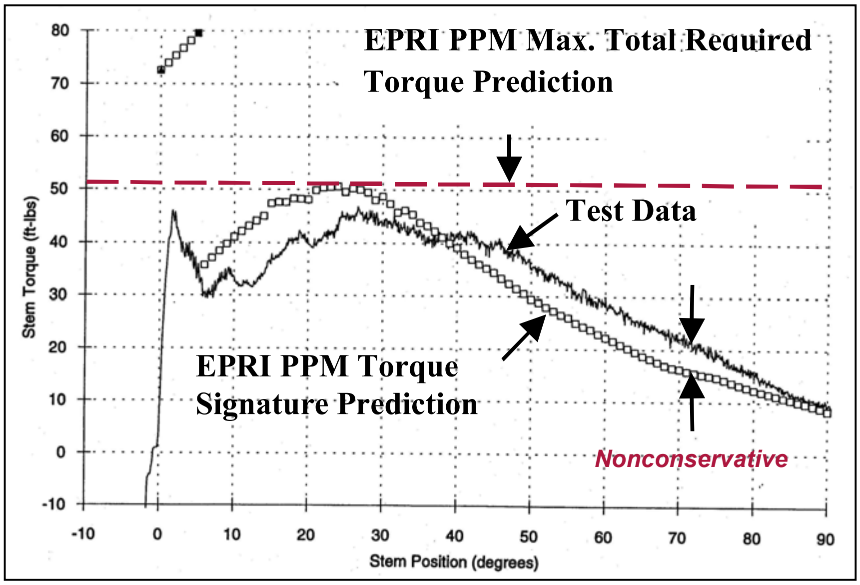


Figure 2: EPRI MOV PPM Required Torque bounds NRC/INEL *compressible flow* test data, but Dynamic Torque predictions (also called Torque Signature predictions) are nonconservative over a large portion of the stroke.



EPRI Valve Test No. F-55



EPRI Valve Test No. I-27

Figure 3: The Total Dynamic Torque predictions (Torque Signature) from EPRI MOV PPM for *incompressible* flow applications can be overly conservative (e.g., top figure) or nonconservative (e.g., bottom figure) depending upon valve type and application.

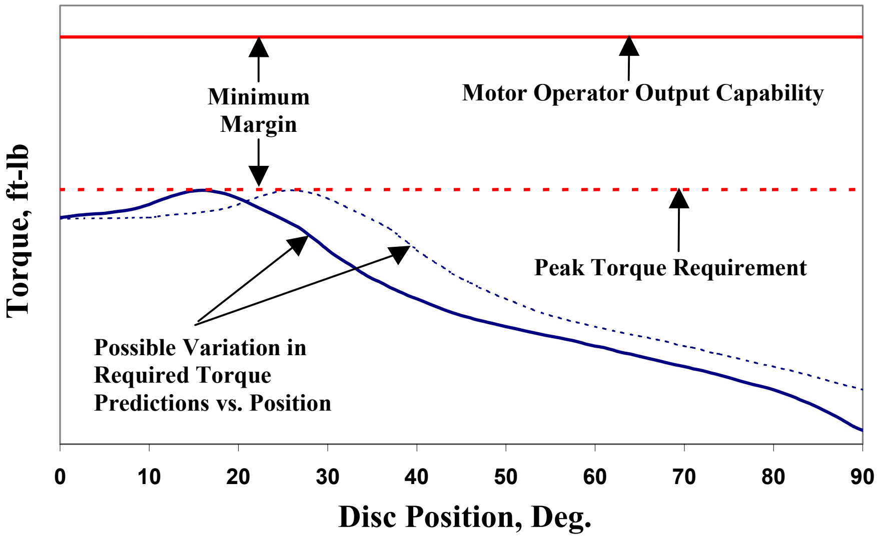


Figure 4A: Typical MOV actuator output is constant throughout the stroke; only peak torque magnitude (regardless of stroke position) dictates the minimum margin.

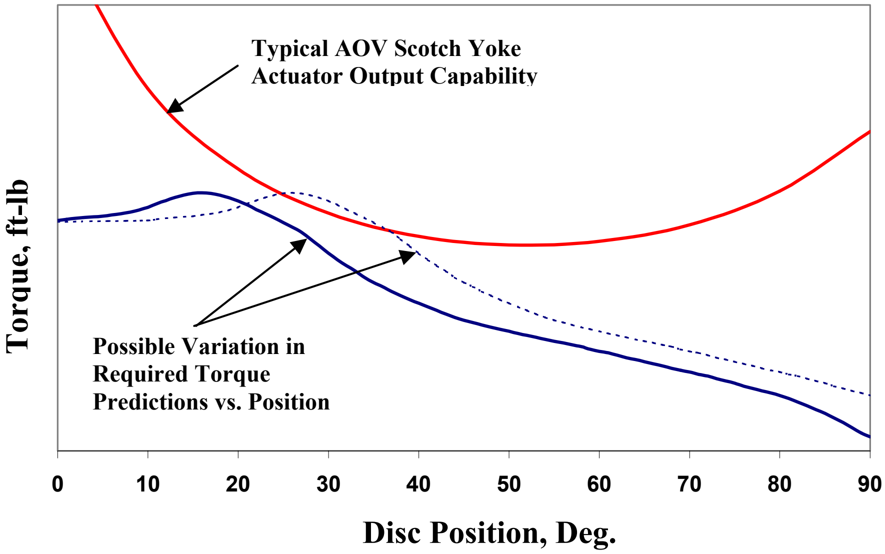


Figure 4B: Typical AOV actuator output varies with position; valve torque requirements must be accurately determined at each stroke position to calculate minimum margin throughout the stroke.

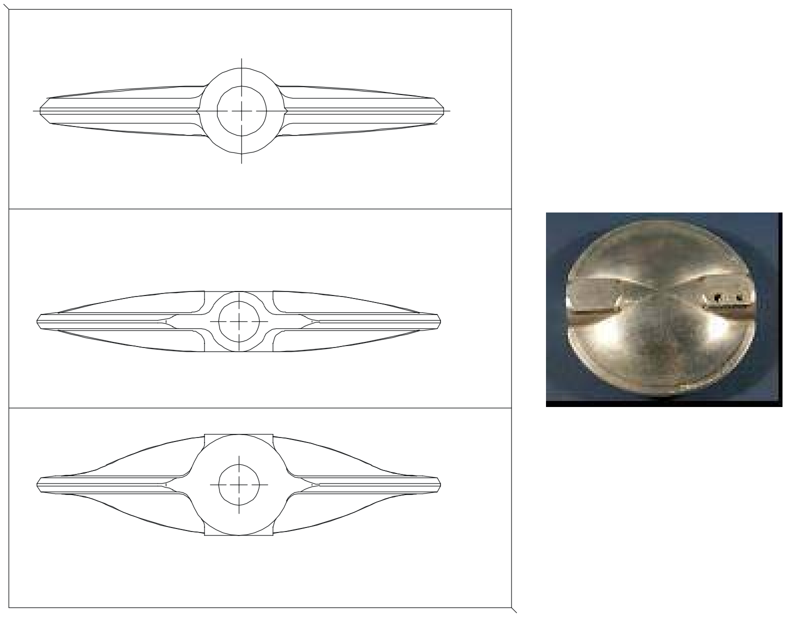


Figure 5: Symmetric discs with different aspect ratios.

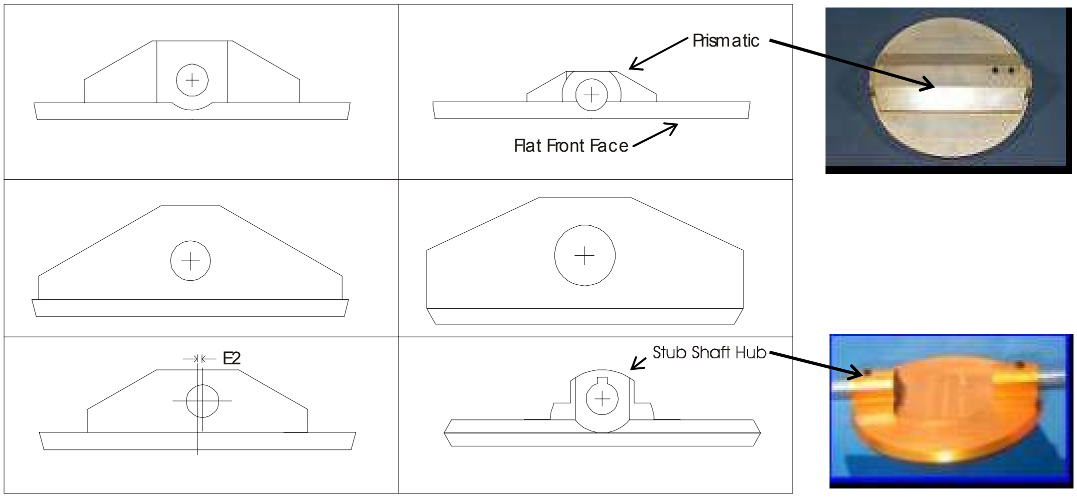


Figure 6: Flat front faced single- and double-offset discs of various aspect ratios and geometries.

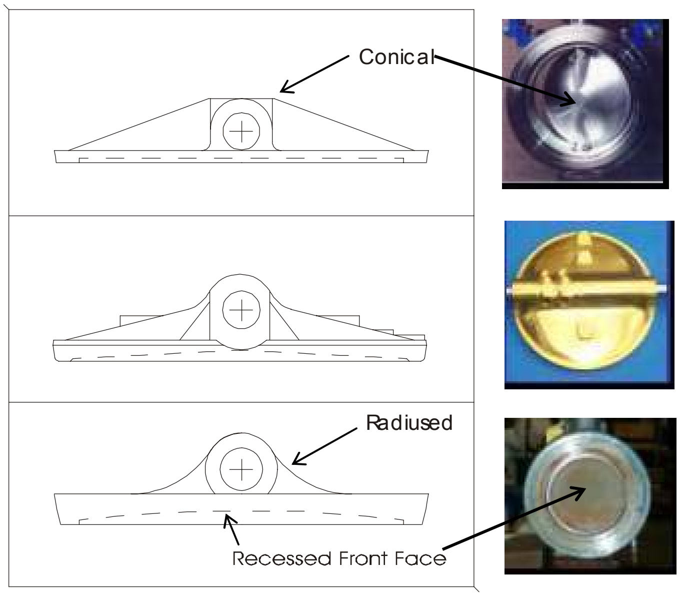
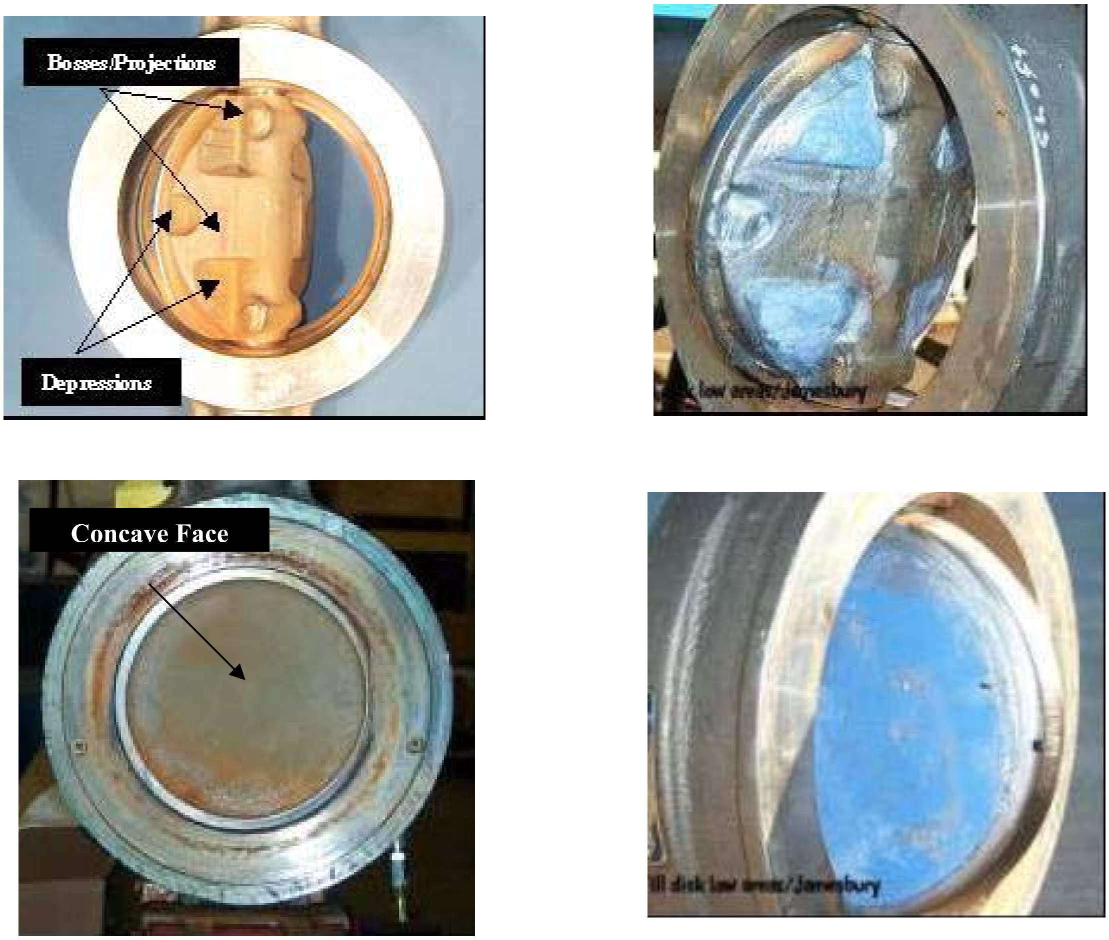


Figure 7: Recessed front faced single- and double-offset disc geometries.



Original Disc from Manufacturer

Disc Faces Streamlined with Filler

Figure 8: Test matrix included sensitivity evaluation of streamlining both the upstream and downstream disc faces on hydrodynamic torque.

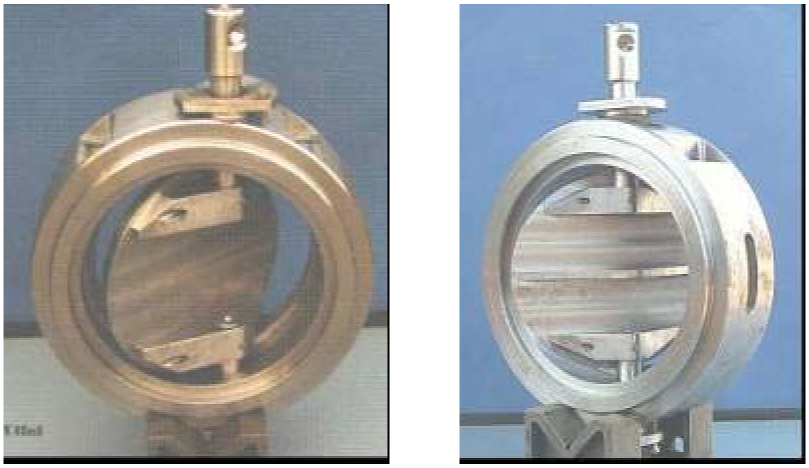


Figure 9: Triple-offset discs with large second offset were included in the test matrix.

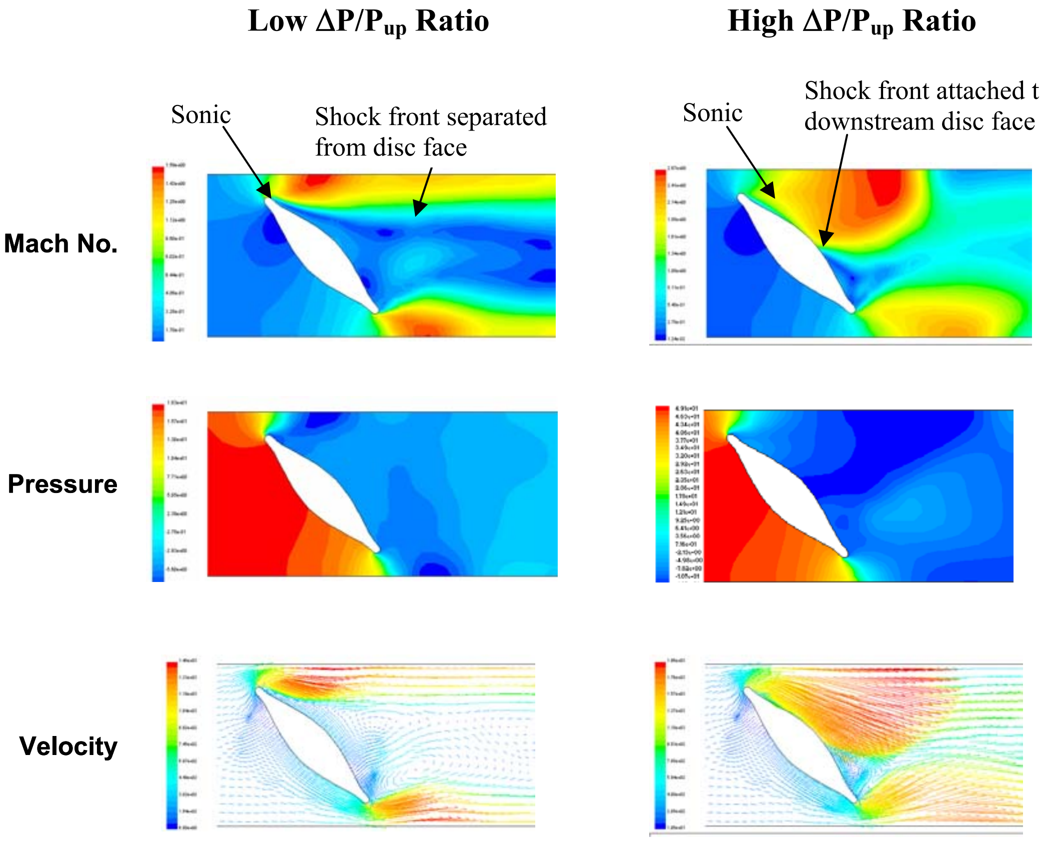


Figure 10: Compressible flow CFD analyses under low and high $\Delta P/P_{up}$ conditions show that shock front reattachment/location on the downstream disc face cause significant changes in pressure distributions, which dictate aerodynamic torque.

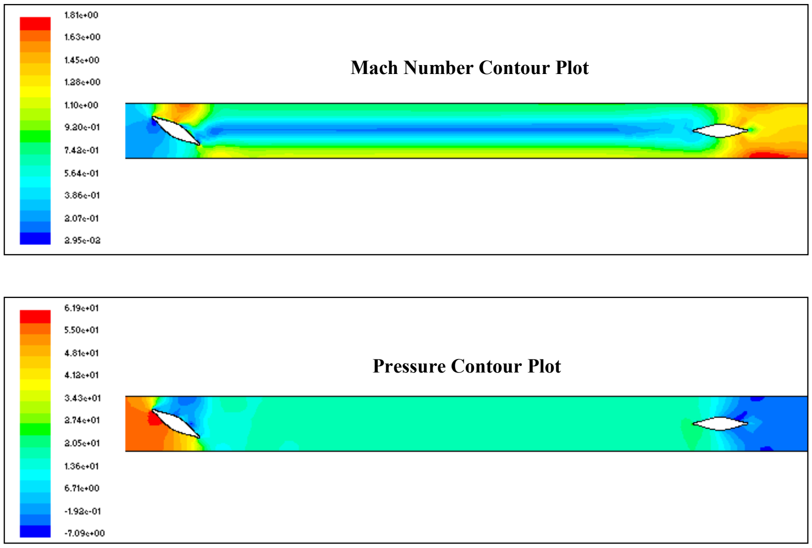
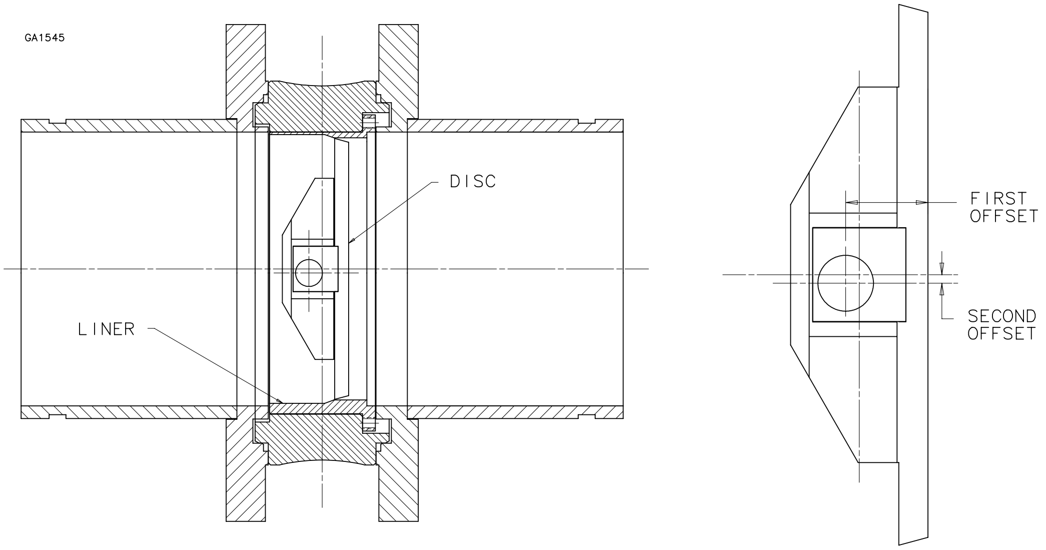
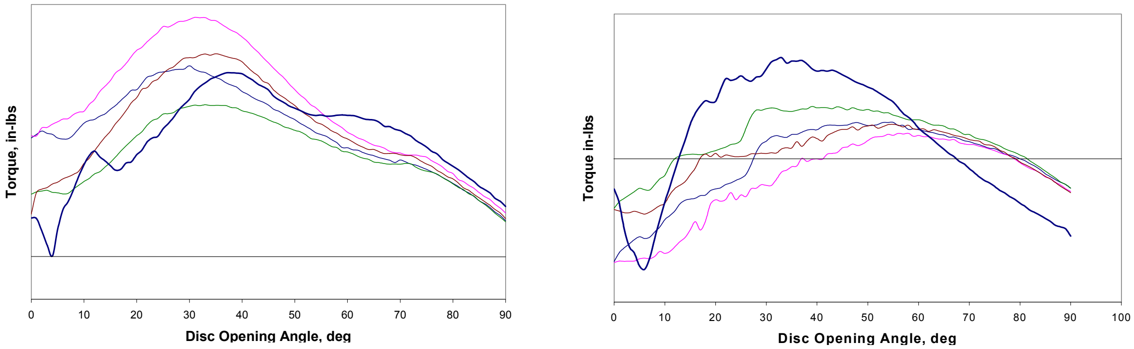


Figure 11: The presence of a downstream valve significantly alters the $\Delta P/P_{up}$ ratio across the upstream valve by causing changes in pressure distribution on its downstream disc face, which dictates the aerodynamic torque.





Shaft Upstream **Shaft Downstream**

Figure 12: Combinations of the first and second offset magnitudes were systematically varied to evaluate their effect on the hydrodynamic torque for double-offset disc valves.

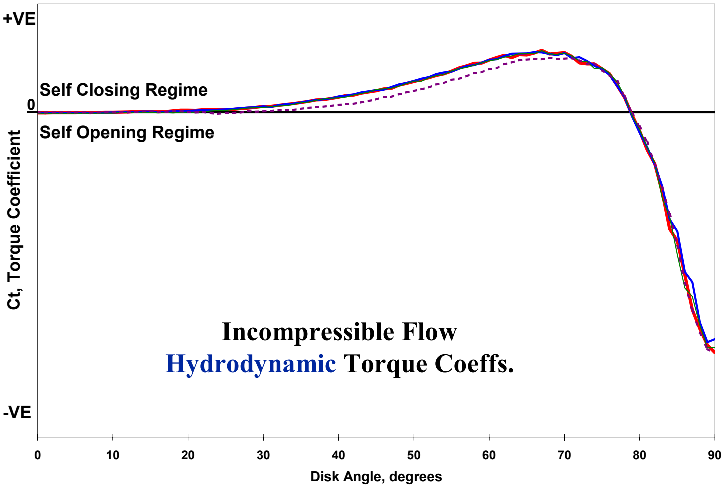


Figure 13: For *incompressible* flow, torque coefficients are independent of pressure drop, therefore torque magnitude is proportional to ΔP, and torque behavior remains the same between low and high ΔP conditions.

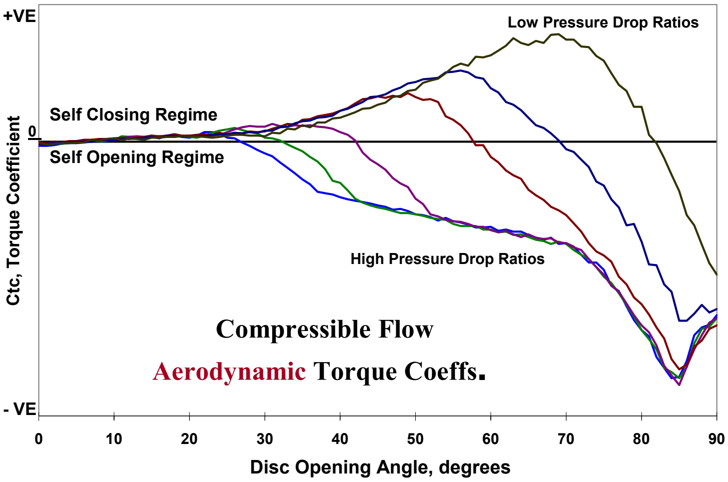


Figure 14: For *compressible flow*, torque coefficients change from self–closing regime to self-opening regime as the $\Delta P/P_{up}$ ratio is increased.

Note: *This explains why NRC/INEL [4,5] tests under containment purge conditions (high $\Delta P/P_{up}$ ratios) exhibited self-opening torque whereas manufacturers predicted self-closing torque (based upon their low $\Delta P/P_{up}$ ratio tests).*

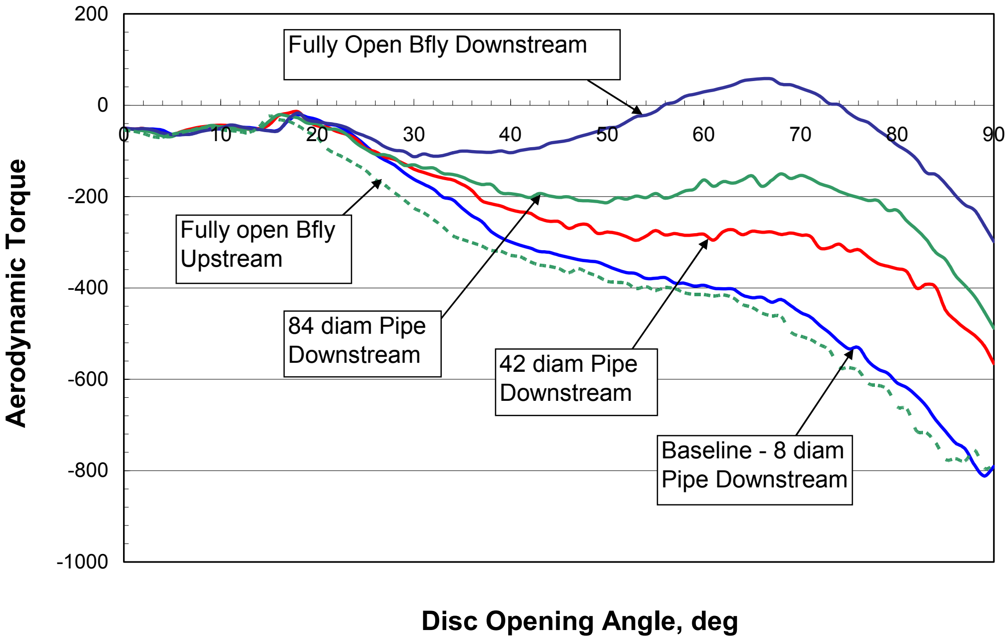
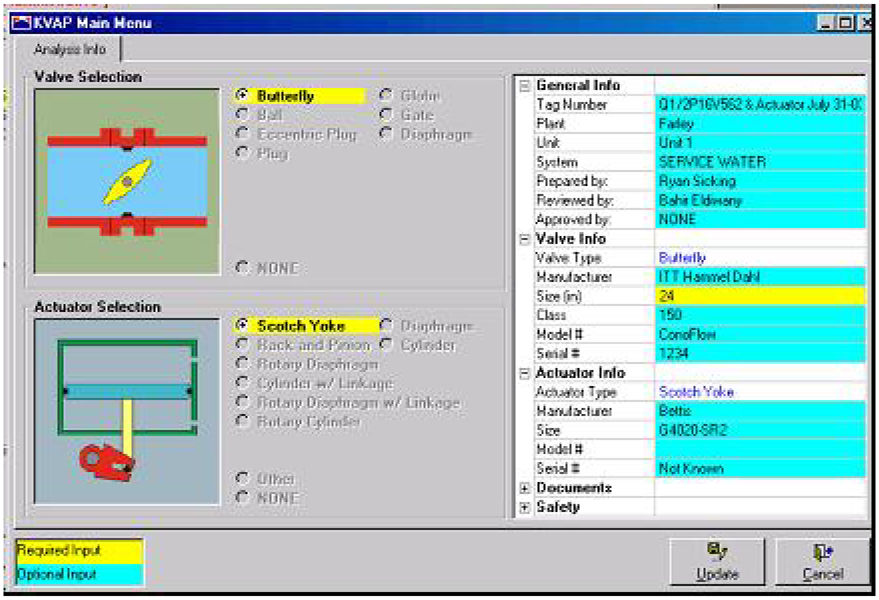


Figure 15: Geometry of downstream flow resistance (e.g., a butterfly valve instead of an equivalent length of pipe) has a profound effect on the aerodynamic torque.

Note: *In this comparison, a fully open downstream butterfly valve significantly lowers aerodynamic torque on upstream butterfly valve, as compared to and equivalent resistance length of downstream pipe (42 diam.). This can increase margin, eliminate unnecessary modifications and allow operation under plant modes previously not permitted.*



Valve Selection

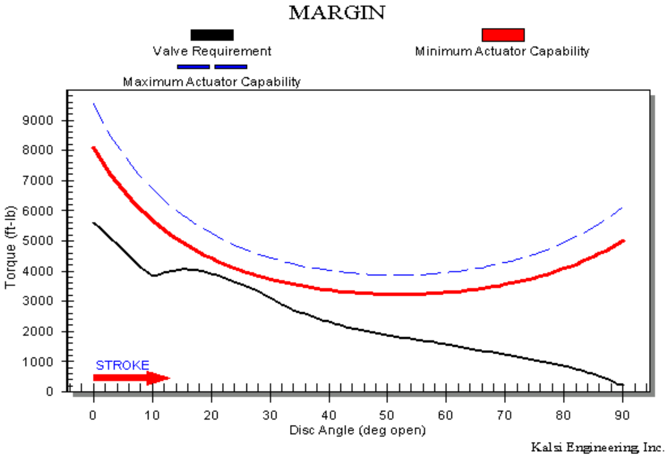
● Butterfly ○ Globe
○ Ball ○ Gate
○ Eccentric Plug ○ Diaphragm
○ Plug
○ NONE

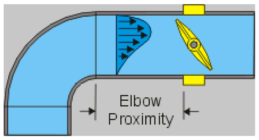
Actuator Selection

● Scotch Yoke ○ Diaphragm
○ Rack and Pinion ○ Cylinder
○ Rotary Diaphragm
○ Cylinder w/ Linkage
○ Rotary Diaphragm w/ Linkage
○ Rotary Cylinder
○ Other
○ NONE

General Info	
Tag Number	Q1/2P16V562 & Actuator July 31-0
Plant	Farley
Unit	Unit 1
System	SERVICE WATER
Prepared by:	Ryan Sicking
Reviewed by:	Bahir Eldiwany
Approved by:	NONE
Valve Info	
Valve Type	Butterfly
Manufacturer	ITT Hammel Dahl
Size (in)	24
Class	150
Model #	ConoFlow
Serial #	1234
Actuator Info	
Actuator Type	Scotch Yoke
Manufacturer	Bettis
Size	G4020-SR2
Model #	
Serial #	Not Known
Documents	
Safety	

Required Input
Optional Input





CONFIG 1: Velocity skew assists CLOSING

Figure 16: Graphically oriented and intuitive user-friendly features of KVAP for input and output screens eliminate the potential for error, and permit efficient calculations by interpolating flow and torque coefficients from the extensive built-in database for the application-specific attributes (e.g., disc geometry, aspect ratio, $\Delta P/P_{up}$ ratio, upstream elbow configuration and proximity).

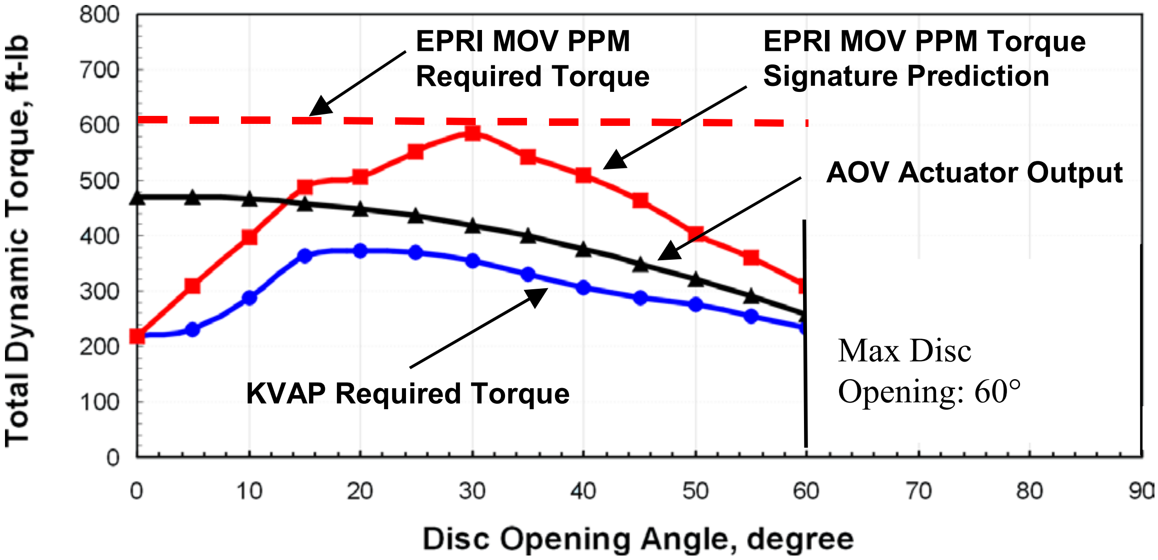


Figure 17: KVAP Margin improvements for 16" butterfly valves in a service water application eliminated the need for modifications indicated by EPRI MOV PPM.

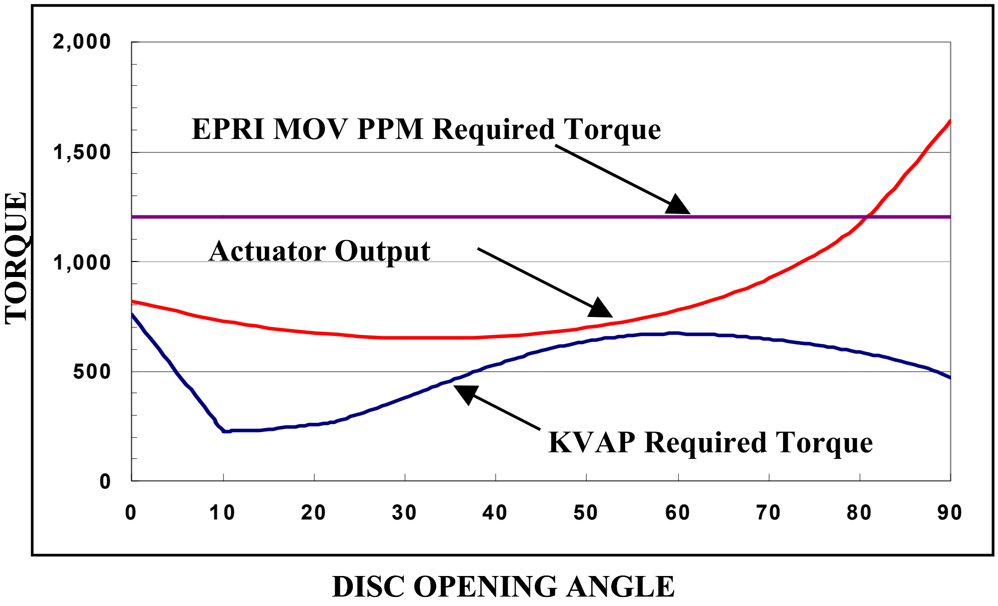


Figure 18: KVAP Margin improvement achieved for 18" butterfly valves in containment isolation application eliminated the need for modifications indicated by EPRI MOV PPM.