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DETAILED CAVITATING FLOW REGIMES FOR CENTRIFUGAL PUMPS, AND HEAD VS. NPSH CURVES

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ABSTRACT

Available published data for detailed cavitation performance of pumps, showing ratios between NPSH values for first inception and head fall-off are presented. For 23 test points, it is found that these ratios vary between ~1.5 and ~18.5, so that no meaningful prediction based on this past experience is as yet possible. Comparative cavitation sigma data in the same "hardware" between water and liquid metals is reviewed. No substantial difference due to fluid change per se is found. However, large cavitation "scale effects" within any given fluid exist.

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I. INTRODUCTION

A major problem in the design of pump impellers in cases where cavitation is probable, and where knowledge of the exact cavitation condition existing is important, is relating the precise cavitation condition to the external pump performance as measured in terms of the conventional parameters resulting in the usual ΔH vs. NPSH curve (Fig. 1, eg.). Details of the existing cavitation regime may be important either because of cavitation damage, or for reasons particular to various applications. For example, it appears that cavitation must be avoided completely in the sodium circulating pumps for the LMFBR in one current design philosophy. It is there desired to use the acoustic signal from collapsing sub-cooled boiling bubbles in the core as a portion of the safety circuit. Distinguishing of such a signal from cavitation is difficult, so that zero cavitation may be required for such a system. On the other hand, if cavitation noise is not prohibitive per se, then cavitation damage becomes the probable limitation, and limited cavitation is permissible. However, without special provisions only the conventional Head vs. NPSH curve can be measured, so that it is desirable to relate this curve to the detailed cavitation regime to adequately design the sodium pumps for this application. Since present analytical techniques are inadequate to provide the necessary detailed information on the structure of the cavitation regime in pumps of this type, it has been necessary in many cases to make detailed model experimental studies using transparent components and sophisticated acoustic instrumentation. Early studies of this sort for cavitating liquid metal pumps (1-3) were made by NASA and Pratt and Whitney - CANEL. While various tests so far performed (1-8, eg.) indicate no significant difference in cavitation performance between liquid metals and water in the same hardware, all detailed tests to date show that cavitation commences at a much higher NPSH than that corresponding to the first fall-off of head or other externally measurable conventional pump parameter.

II. Compilation and Presentation of Available Data

A. Comparison of Cavitation Inception between Water and Liquid Metals

Various comparative cavitation sigma tests between water and liquid metals in the same "hardware", including particularly pumps and venturis, have been made over the last decade and reported in the literature (1-8, eg.). While most of the work concerns sodium, a mercury pump was tested in this laboratory (5). The present author has summarized the comparative test data so far available elsewhere (4). While large cavitation sigma "scale effects" exist for all liquids due to various causes, the presently available data, which is quite varied and considerable (as well as theoretical considerations) indicate no significant difference in cavitation sigmas due to different liquids per se. The effects of gas content are also not likely to be substantial as long as they are within the usual ranges found in engineering equipment. The presently available gas content data has been summarized elsewhere (9) by the present author and others.

B. Detailed Pump Cavitating Flow Regimes - Head vs. NPSH

Detailed pump cavitation tests wherein the earliest initiation of cavitation is detected either acoustically or visually* are reported over the past ~15 years from various laboratories in the U.S. and abroad, such as Pratt and Whitney - CANAL (1,2), NASA-Lewis (3), NEL (10-14), Neratoom (7, 8, 15), UKAEC-Risley (16), and our own laboratory (5). From these sources it is possible to compute ratios between the NPSH corresponding to the first visual or acoustic appearance of cavitation and $NPSH_{crit}$, corresponding to conventionally defined cavitation inception, i.e., either 2 or 3% head drop-off. Twenty-three such tests points have been found from this reported data. These are listed in Table 1 along with the conventional pump parameters as far as possible. They are plotted

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* For first inception, the methods appear to be equivalent.

on Fig. 1, which is a generalized Head vs. NPSH curve, normalized to non-cavitating head and NPSH $_{crit}$. While the scatter of points is considerable, I have divided the axis very roughly into regions of possible damage and noise, possible noise but probably no damage, and zero noise or damage. Of course these divisions assume "average" pump designs according to the present authors opinions, and are not in any case directly backed by experimental evidence at this time.

The data is further grouped in Fig. 2, showing "frequency of event" vs. ratio of NPSH for inception ($NPSH_{Inc.}$) to $NPSH_{crit}$. In this way it is seen that the most probable value for this ratio is ~2.5, but in some cases it is in the range 15 - 20. It appears that for "good" pumps (high S = suction specific speed), the ratio tends to be large, whereas it is moderate for moderate S pumps (12), but this is not always the case. At this point I know of no good explanation for the wide variation of this NPSH ratio. It thus still appears that <u>no</u> prediction of the detailed cavitation behavior of a new pump design, based on published past experience along, is meaningful. Hence, either detailed transparent (or acoustically instrumented) model tests, or the development of more realistic computing models than are presently available, seems necessary to assure required pump performance for such cavitation—sensitive applications as the sodium pumps for the LMFBR. The rough division of the overall performance regime shown in Fig. 1 seems to provide as accurate a general prediction as is presently possible. This indicates that an NPSH "safety factor" of ~4 is necessary to avoid the probability of damage, and ~10 to avoid bubble noise. Separate detailed tests in water and sodium are probably not necessary, if full-scale water tests are made.

III. CONCLUSIONS

The following general conclusions seem possible at this time.

1. No significant differences engineering-wise in cavitation performance of pumps between different liquids exist due to the change in liquid per se, but large cavitation "scale effects" exist for all liquids. This statement does not include damage considerations. Thus separate detailed cavitation performance tests between water and sodium, eg., are probably not necessary, if damage considerations are not involved. However, the only sure way to avoid damage (and bubble noise) is to assure this complete absence of cavitation in the pump. This will in general require an NPSH many times that for head fall-off (perhaps ~10 x). However, limited cavitation, requiring an NPSH "safety factor" of ~4, may be sufficient if only damage (and not noise) is the consideration.

2. Examination of 23 separate test points shows that the "most probable" ratio between NPSH for first inception and head fall-off is ~2.5. However, several pumps, particularly those with high suction specific speed, show ratios in the range 15 - 20.

3. Prediction of detailed cavitation behavior of a new pump design is not possible from the published past experience. Hence it appears that either detailed visually or acoustically instrumented model tests, or the development of improved computing models, are necessary for cavitation-sensitive applications such as the sodium circulating pumps for fast breeder reactors (LMFBR).

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Ref. Point No.	Identification	N RPM	ΔH ft	Q GPM	$NPSH_c$ ft.	N_s US units	S_{cav} US units	$\frac{NPSH}{NPSH_c}$	S_{min} US units	Type	Ref	Remarks
1	Neratoom No. 1	960	260	22.9	11.3	2.18	23.7	1.75	15.5	Centrifugal	7	Visible Init. of 1 mm cav. plume
2	" No. 2	960	260	22.9	11.3	2.18	23.7	2.50	11.9	Same as No. 1	7	First Acous. Inception
3	Risley Model	960	~260	5.3	20.0	1.08	7.40	3.86	2.72	Centrifugal	16	First Acous. Incep.
4	Risley Primary	960	~260	20.5	14.8	2.12	8.00	2.62	3.88	Double Suction Centr.	16	" "
5	Risley Secondary	960	~260	17.7	54.0	1.97	6.48	2.10	4.57	Centrifugal	16	" "
6	NEL No 2	~1500	~150	~1.0	~15	1.10	6.18	3.39	2.47	"	11	" "
7	NEL No. 11-C	707	—	—	—	3.12	10.3	7.33	2.30	"	12	" " 0.5 Q_{DES}
8	PWA No. 1	2460	~60	0.750	7.0	20.9	17.5	11.5	2.79	Mixed Flow	1	First Visible
9	PWA No. 2	4250	~150	0.400	7.0	20.9	15.7	4.35	5.23	"	1	Small Cavit. Plume
10	PWA No. 3	2460	~60	0.750	6.0	20.9	17.5	3.33	7.09	"	1	"
11	PWA No. 4	"	~60	10.5	17.0	20.9	9.55	1.93	5.84	"	1	" 1.4 QDES
12	NASH No. 1	"	—	—	33.0	Axial Flow	16.6	3.50	6.49	Axial Flow	2	First Acoust.
13	NEL No. 3	1500	—	—	1.6	1.5	10.5	16.3	1.30	Centrifugal	12	" "

Ref. Point No.	Identification	N RPM	ΔH ft	Q GPM	$NPSH_c$ ft.	N_s US units	S_{crit} US units	$NPSH/NPSH_c$	S_{incip} US units	Type	Ref	Remarks
14	NEL #4-a	2960	—	—	—	0.86	12.3	16.7	1.49	Centrifugal	12	1st Accept. Boiler Feed
15	NEL #4-b	1440	—	—	—	0.86	10.7	10.0	1.90	"	12	" / 0.8 Q.
16-a	NEL #5-a	992	—	—	—	2.63	5.81	5.6	1.60	"	12	Double " suct. / Q_{BEP}.
16-b	NEL #5-b	992	—	—	—	2.63	5.85	3.75	2.18	"	12	" / 1.2 Q_{BEP}
17	NEL No. 6	1305	—	—	—	8.75	6.43	2.57	3.16	"	12	" / Q_{BEP}
18	NEL No. 7	1507	—	—	—	1.85	10.5	2.72	3.85	"	12	" / "
19	NEL No. 8	2259	—	—	—	1.85	9.6	2.2	5.25	"	12	" / "
20	NEL No. 9	2259	—	—	—	1.85	13.1	3.0	5.55	"	12	" / "
21	NEL No. 10	2259	—	—	—	2.00	—	2.67	—	"	12	" / "
22	NEL No. 11-a	1179	—	—	—	3.12	11.2	8.24	2.32	"	12	" / "
23	NEL No. 11-b	1179	—	—	—	3.12	13.6	18.3	1.54	"	12	" / "

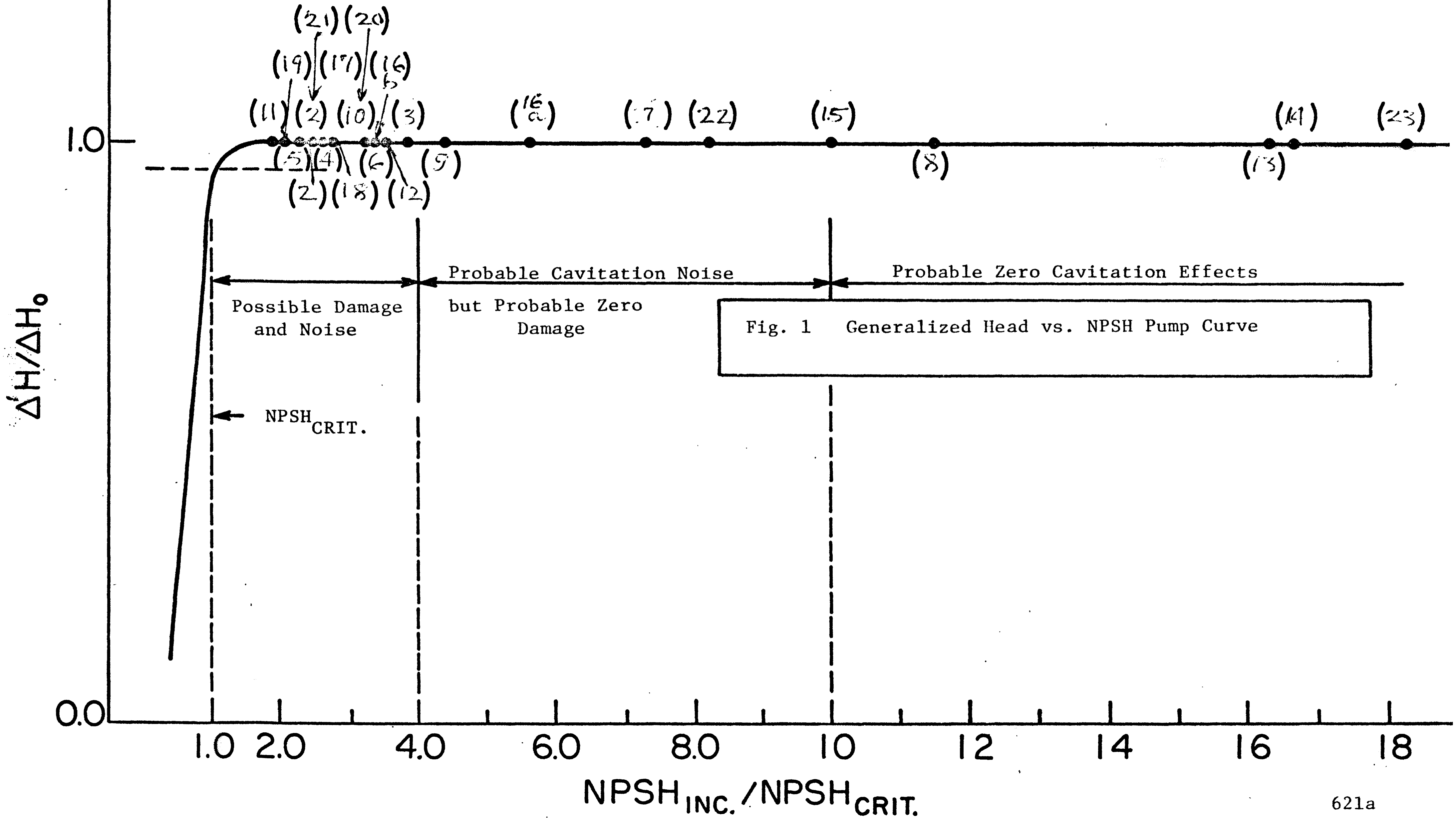

Fig. 1 Generalized Head vs. NPSH Pump Curve

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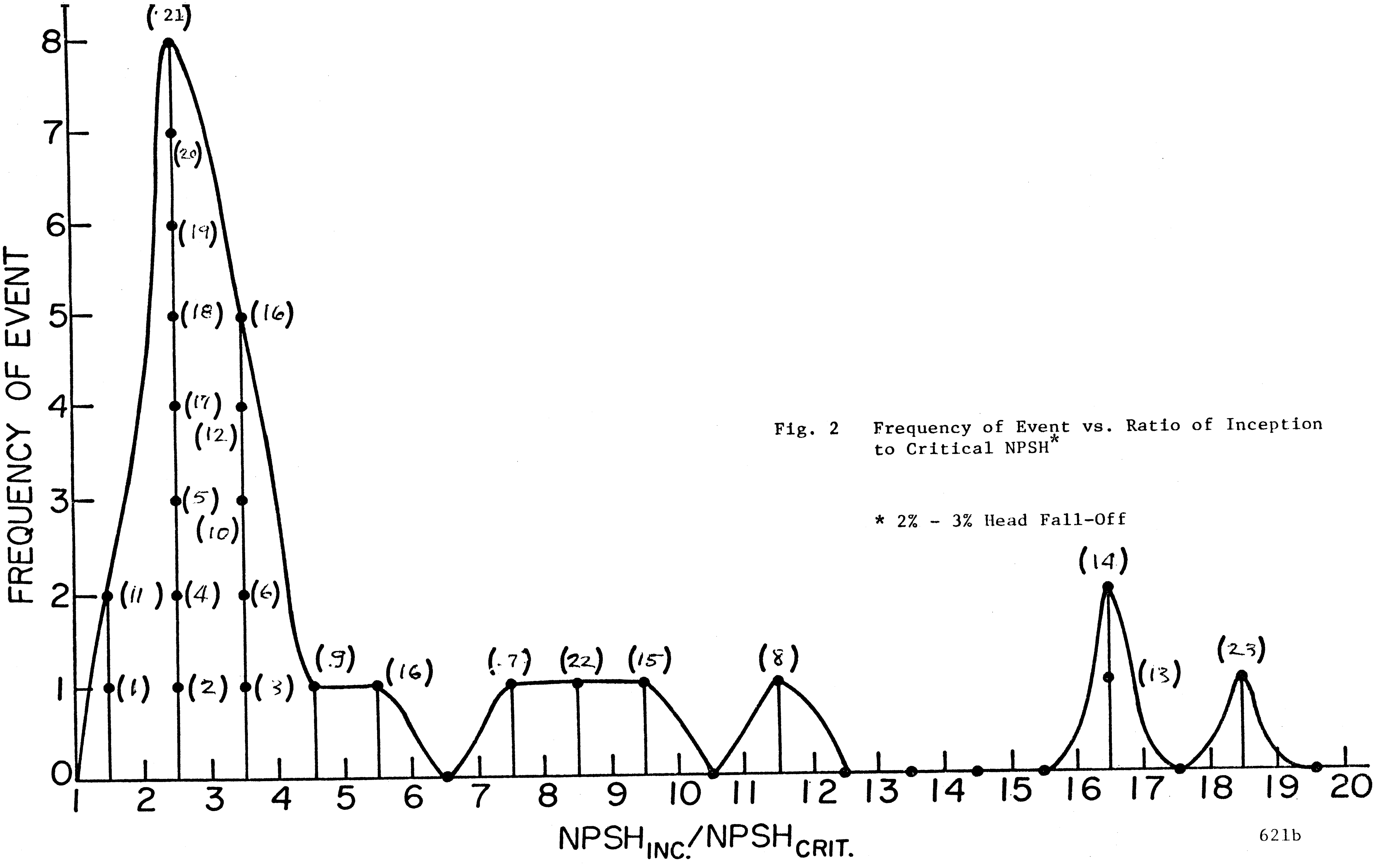

Fig. 2 Frequency of Event vs. Ratio of Inception to Critical NPSH*

* 2% - 3% Head Fall-Off

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