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- c. Order the CIP to reflect their critical dependencies, creating an influence diagram with directed causal links with no feedback paths.
- d. Create the Bayesian belief network by defining conditional probability tables capturing consensus beliefs on the probable outcome of any CIP.
- e. Consider possible interactions and capture their expected influences on the network, as optional CIP.
- f. Analyze the resultant model probabilities to assess the overall hazard level.



Figure 5. Aviation System Risk Model (ASRM) [20]

An iterative process to develop consensus BBN models of fault propagation incorporating conditional probability estimates for fault propagation and responses.

The resultant BBN model demonstrated the ability of a BBN to capture a host of causal risk factors, their interactions and potential mitigations, and their influence on flight adverse consequences. The full model is too large and complex to be displayed here. The [Figure 5](#) shows the process associated with a single category.



Figure 6. Decomposed Hazard Analysis [22]

This diagram depicts the network for a single critical mishap and associated causal links, including secondary events.

Phase II concluded with a positive outlook on the BBN HIRA model's ability to assist in eliciting and accommodating expert judgement in assessing complex hazard and risk architectures, and understanding of critical influences on system safety. NAVAIR and NPS stakeholders recommended further work focused on launch and mishap of concern for airworthiness for specific aspects of UAS test missions and environments.

2.5. Phase III: NPS/NAVAR UAS IPC Challenge: Intersect Flight Governance Phase III (OQ-REY) Demo (OJ, 11A, OJ, 11FS)

Phase III addressed two UAS applications: The NPS RASCAL UAS flight test, and NPS Lockheed rotary wing UAS overwater missions. Both were assessed for four modeling categories: crash, air collision, non-commission and launch & recovery. Influence network models were completed and consensus for all eight mishap cases, complete with mitigation and conditional probability tables.

In their final meeting, the UAS panel and the project team successfully completed a launch & recovery BBN model including all conditional probability estimates, with consensus from the UAS panel.

A significant advance in the ASRM approach for IC airworthiness assessment was developed in this phase. In consultation with NAVAIR stakeholders, early in the ASRM process the team selected the critical airworthiness mishap categories for the UAS mission, and defined through a build focused network of causal risk factors and potential mitigations for the more significant mishap categories, e.g. the RASCAL crash network in [Figure 7](#). This approach greatly reduces model scope and complexity, improving comprehension and confidence in the BBN and the resultant probability estimates.



Figure 7. Crash BBN Model [22]

The BBN approach is consistent with the mishap of concern, with the relevant causal risk factor network and mitigation shown. The critical component and conditional probability tables and response tables below for a complete presentation of the mishap case. When complete, each mishap case will be modeled and all mishap cases will be modeled. A complete hazard analysis.

Additional flexibility was provided by the identification and continuation of two separate sources of BBN software that gave equivalent BBN results:

- the commercial Hugin Expert application and
- the OpenBay Network Inference (ONIN) and Inference Modeling Language and Learning Engine (IMLE) BBN software developed by University of Pittsburgh's Decision Systems Laboratory, available with a free academic use license.

such as 150000, 400000 and 1500000 results that represent of angle of a steering system is scheduled in [Table 12](#) [22] (2) hence, correct understanding regarding angle of a steering system is essential for correct operation. As well as angle of control commensurate with it and related steering system.

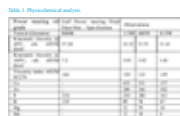


Figure 8. Steering system of a ball bearing [22]



Figure 9. Ball bearing [22]

Field vehicles were reorganized based on four parameters such as region, application, Off-road, On-road and kilometers coverage. It was observed that independent of all the above parameters, the oil misting was observed at all models and all regions with kilometers ranging from 10000 kilometers to 150000 kilometers.

Field steering pump has been operated into two equal halves as shown in [Figure 10](#) [22]. These major observations listed as follows:

1. Single lip seal was used as shaft seal. Single lip seal used capable to protect oil at one direction. In the failed steering pump, one has shown that misting of oil from flow from inside to outside the steering pump. But not oriented to prevent ingress of oil.

Refer [Figure 11](#) [22]. Single lip seal had one garter spring in it and lip opens during negative pressure demand normal seal. Lip reverts back to original position when no negative pressure exists near seal. That

entry side of seal is projecting towards engine ball face to appearing towards pump. Lip of single lip seal will open if any vacuum created at pump. Single lip seal is shown in [Figure 12](#) [22] on both the side of oil seal. If one lip opens due to some negative pressure of single lip seal, the other lip reverts to opposite direction and prevents oil flow from one pipe to another pipe.

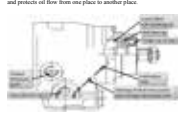


Figure 10. Failed steering pump [22]

Figure 11. Oil misting [22]

2. Ball bearing had a superior lubricating ball provided from reaction point as shown in [Figure 13](#). Ball bearing could not offer resistance to oil flow from steering pump as oil can easily pass through gap between ball and cage without restriction.



Figure 12. Ball bearing [22]

[Figure 13](#) shows ball bearing of failed steering pump. As shown in [Figure 14](#) [22], failed bearing does not require lubrication and tend to produce more heat restriction than ball bearing of failed steering pump. Thus, failed bearing can perform independently and becomes unable to restrict flow in existing position to holding face of steering pump.

3. In failed steering pump, a cavity exists behind ball bearing to lubricate ball bearing.

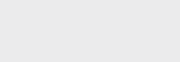


Figure 13. Ball bearing [22]

The parameters describing the bubble response include the normalized bubble radius $R_{b,0}$, $R_{b,1}$, and $R_{b,2}$ that correspond to saturation pressure P_1 , P_2 , and P_3 , and flow orientation with normalized exposure time t . First, the Rayleigh-Plesset [Equation 1](#) bubble radius subjected the viscosity and surface tension is solved numerically on ODE under three operational pressure P_1 , P_2 , and P_3 where all radius of spherical bubble have the same operational collapse time. However, $R_{b,1}$ (P_1) was observed with the largest radius, $R_{b,2}$ (P_2) had the lowest radius, $R_{b,3}$ (P_3) had the highest radius. $R_{b,2}$ had shown the same radius at 70 °F. This result showed the temperature's impact upon operational bubble collapse radius.



Figure 14. Bubble radius vs. time at different exposure rates [22]

Figure 15. Bubble radius vs. time at 70 °F [22]

Rayleigh-Plesset [Equation 1](#) bubble radius at 70 °F with viscosity and surface tension is solved numerically on ODE under three operational pressure P_1 , P_2 , and P_3 where all radius of spherical bubble have the same operational collapse time. The normalized collapse time of $R_{b,1}$ was observed to quickly respond to P_1 due to higher external force. The result is that radius $R_{b,1}$ has a longer operational time with P_1 , which has low external force and a shorter exposure time.

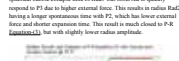


Figure 16. Bubble radius vs. time at 2500 R.P.M. [22]

It was subsequently proposed that the impact of bubble KSC-E upon a nearby surface was the primary energy for causing cavitation damage. The dynamic behavior of the cavitation bubbles resulting from the rapidly changing pressure inside the hydraulic machine is studied by the solution of the generalized version of the simplified Rayleigh-Plesset equation. The model of the cavitation erosion potential is based on the estimation of the energy dissipated by the collapse of the cavitation bubbles. It is assumed that all the energy dissipated during the bubble collapse is used to form the shock wave propagating from the bubble's center. As part of the shock wave energy emitted towards the solid surface is supposed to represent the erosion potential.



Figure 17. Bubble radius vs. time at 2500 R.P.M. [22]

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