REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
01/12/2020

2. REPORT TYPE
Final Technical Report

3. DATES COVERED *(From - To)*
30-11-2017 - 29-11-2020

4. TITLE AND SUBTITLE
NICOP - Analytical and Numerical Methods for Identifying Principal Components of Heterogeneous Physical Data

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N62909-18-1-2033

5c. PROGRAM ELEMENT NUMBER
1000007558 (NICOP)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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8. PERFORMING ORGANIZATION REPORT NUMBER
N62909-18-1-2033_FTR

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research Global
86 Blenheim Crescent
Ruislip MX HA4 7HB
United Kingdom

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The objective of this NICOP project is the development and assessment of analytical and numerical methods for identifying principal components from heterogeneous physical data, for application in ship hydrodynamics, hydroelasticity, and naval systems. The long-term objective is the establishment of rigorous methods for a better assessment, understanding, representation, dimensionality reduction, and prediction of the physics of complex phenomena, such as those involved in the operation of military ships, subject to a variety of environmental and operating conditions. This document summarizes the project achievements (final technical report).

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Matteo Diez
					19b. TELEPHONE NUMBER *(Include area code)*
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Final Technical Report for NICOP Project

Analytical and Numerical Methods for Identifying Principal Components of Heterogeneous Physical Data

Award No.:	N62909-18-1-2033
Period of performance:	11/30/2017 – 11/29/2020
End of reporting period:	11/29/2020
PI:	Dr. Matteo Diez
Co-PI:	Dr. Andrea Serani

1 December 2020

Abstract

The objective of this NICOP project is the development and assessment of analytical and numerical methods for identifying principal components from heterogeneous physical data, for application in ship hydrodynamics, hydroelasticity, and naval systems. The long-term objective is the establishment of rigorous methods for a better assessment, understanding, representation, dimensionality reduction, and prediction of the physics of complex phenomena, such as those involved in the operation of military ships, subject to a variety of environmental and operating conditions. This document summarizes the project achievements (final technical report).

Background

In the last decades, the process of assessing complex engineering systems has been significantly modified by the availability of high-fidelity simulation tools, with high-performance computing systems. Simulation-based analysis and optimization architectures are constantly developed, specialized for different engineering fields, with large computational simulations organized in order to evaluate the performance of a design operating in specific environmental conditions. Below the surface of this revolution, there is the constant search for improvements, imposed by an increased global market competition. Efficient methods and architectures are required in order to identify safer and more cost-effective operations, through exploration of larger physical spaces possibly addressing high-fidelity multi-disciplinary and multi-objective analyses with validation to experimental data. In the last years, the collaborative effort by INSEAN (Marine Technology Research Institute, part of the National Research Council of Italy, now INM, Institute of Marine Engineering) and University of Iowa (UI), supported by ONR/ONRG, has focused on simulation-based design (SBD) optimization methods. INSEAN and UI have successfully combined high-fidelity deterministic design optimization and uncertainty quantification (UQ) methods for milestone achievements in stochastic optimization. In addition, INSEAN and UI collaboration on fluid-structure interaction (FSI) has been successfully applying one- and two-way CFD/CSD (computational fluid dynamic/computational structural dynamic) coupling to both unit and real-world applications. These achievements provide a solid foundation for next step research toward an augmented physical space assessment, allowing for a better understanding of the physics of complex phenomena, using distributed and lumped heterogeneous data. Simulation-based design tools developed in earlier research will be extended and applied to the optimization of physical data exploration, assessment, representation, dimensionality reduction, and prediction.

Objective

The objective of the present research is the development and assessment of analytical and numerical methods for identifying principal components from heterogeneous physical data, for application in ship hydrodynamics, hydroelasticity, and naval systems. The long-term objective is the establishment of rigorous methods for a better assessment, understanding, representation, dimensionality reduction, and prediction of the physics of complex phenomena, such as those involved in the operation of military ships, subject to environmental and operational uncertainty. The formulation of the overall methodology will capitalize on the modularity and flexibility of the optimization toolbox developed in the last years under ONR/ONRG support. The peculiarities of the methods proposed will constitute an original contribution to the ship hydrodynamics field, meeting the goals of the "Platform Design and Survivability" US Naval S&T Focus Area.

Technical approach

The approach will include linear and nonlinear methods for distributed and lumped physical data assessment, variability breakdown, and dimensionality reduction. Linear methods include principal component analysis (PCA) techniques, whereas nonlinear methods include kernel and local PCA (KPCA, LPCA) combined with clustering techniques, and deep autoencoders (DAE). In order to populate efficiently the physical database, extensions of methodologies available in the toolbox will be carryout with specific focus on adaptive metamodelling techniques and hybrid global/local multi-objective bio-inspired algorithms. Applications of interest to the US Navy will be identified with discussion with ONR/ONRG. Potential problems of interest include augmented physical space assessment for complex hydrodynamics and FSI/hydroelasticity, dimensionality reduction of simulation and experimental data, extended validation of simulations versus experiments by principal components. In regard to the management approach, the current NICOP proposal stands alone. However, it will benefit by the use of the code CFDShip-Iowa, provided by UI. Furthermore, the activities will be conducted in collaboration with NATO S&T task groups AVT-252 "Stochastic Design Optimization for Naval and Aero Military Vehicles," AVT-280 "Evaluation of Prediction Methods for Ship Performance in Heavy Weather," and AVT-ET-185 "Goal-driven, Multi-fidelity Approaches for Military Vehicle System-level Design." George Washington University (GWU) will also collaborate to these activities by providing experimental data of complex flows.

The project activities are organized in tasks. Table 1 reports a summary of the tasks, as they appear in the proposal Statement of Work (SoW).

Table 1: Project tasks

Task No.	Task Title	Description
1	Linear methods for physical data assessment and dimensionality reduction	The linear PCA is extended and applied to disjoint Hilbert spaces including heterogeneous geometry and/or physical data (both distributed or lumped). Principal components and modes are produced for data assessment, interpretation, dimensionality reduction, and prediction.
2	Nonlinear methods for physical data assessment and dimensionality reduction	Nonlinear methods are formulated and applied to disjoint Hilbert spaces including heterogeneous geometry and/or physical data (both distributed or lumped). Extended (in the nonlinear sense) principal components and modes are produced for data assessment, interpretation, dimensionality reduction, and prediction.
3	Toolbox development	Adaptive metamodels and hybrid global/local multi-objective bio-inspired algorithms are developed and applied to populate the physical database.
4	Applications	Applications of interest to the US Navy are identified. Problems of interest are formulated and solved using the methodologies developed in Tasks 1-3.

The project schedule is shown in Table 2, including description of milestones and anticipated month of achievement after contract awarded (also included in the proposal).

Table 2: Project schedule

Task/Sub Task	Description of milestone	Number of months after contract awarded
4	Identification problems of interest	6
1	Development and testing of linear methods on simplified problems	18
2	Development and testing of nonlinear methods on simplified problems	24
3	Development and testing of overall toolbox methodologies on simplified problems	30
4	Solution of problems of interest to the US Navy using linear and nonlinear methods	36

Project accomplishments at the end of the reporting period (final)

Task 1:

- KLE/PCA methodologies were developed and applied to the DTMB 5415 design-space assessment and dimensionality reduction based on geometric data only and compared to nonlinear methods (D'Agostino et al., 2018a,b). KLE/PCA methodologies were extended to combined/heterogeneous geometry- and physics-based data. Formulation and results including multiple conditions were published in Serani and Diez (2018), Serani et al. (2018, 2019b), and D'Agostino et al. (2018c). The research was conducted data in collaboration with AVT-252 and AVT-331.
- KLE/PCA methods were formulated for and applied to the assessment and dimensionality reduction of design spaces provided by different shape modification methods, namely free-from deformation, radial basis functions, and global modification functions. Results for the DTMB 5415 were published in a journal paper (D'Agostino et al., 2020a).
- POD/PCA was applied to buoyant jet data in a stratified environment (provided by GWU) and the results were included in Serani et al. 2019a and D'Agostino et al. (2020b).
- Preliminary studies based on linear models have were performed to assess and nowcast ship motions. Specifically, an adaptive and augmented *dynamic mode decomposition* (aDMD) was formulated and applied to CFD data from AVT-280 (5415M in heavy weather). In parallel, an adaptive *normal-form mode decomposition* (NFMD) method has been developed and applied to the same CFD data.
- Dynamic decomposition methods, such as aDMD and NFMD were extended to heterogeneous data sets composed by ship motions and distributed variables (such as pressure, immersion probes, etc.) to nowcast ship motions and possibly structural loads. Simulations performed within AVT-280 and follow-on AVT-348 were used as test case.
- KLE/PCA approaches of heterogeneous data (geometry and physics) for the dimensionality reduction and reduced order modeling of design spaces were extended to problems of interests within AVT-331 (see e.g., Beran et al., 2020). Moreover, integration of KLE/PCA with the active subspace method (ASM) is the subject of a paper at the AIAA SciTech 2021 Forum (Khan et al. 2021).

Task 2:

- Nonlinear methodologies based on LCPA, KPCA, and DAE were developed and applied to the DTMB 5415 design-space assessment and dimensionality reduction based on geometric data only (D'Agostino et al., 2018a,b) with comparison to linear KLE/PCA. Extensions to combined/heterogeneous geometry- and physics-based data were presented in Serani et al. (2018, 2019e) and D'Agostino et al. (2018c).
- K-means clustering and LPCA methods were applied to a jet in a uniform environment and a buoyant jet in a stratified environment (Serani et al., 2019a; D'Agostino et al., 2020b). Data were provided by GWU.

Moreover, k-means clustering of propeller-wake PIV data was performed to identify topologies of tip vortex instability mechanisms (D'Agostino et al. 2020b). Furthermore, k-means clustering of wave sequence data of 5415M in heavy weather was performed within AVT-280 to identify characteristics leading to extreme roll angles (Walree et al., 2020a,b).

- Studies on long-short term memory (LSTM) neural networks, recurrent neural networks (RNN) and gated recurrent unit (GRU) were performed as extensions of dynamic decomposition/prediction methods to nonlinear approaches for ship motions/loads forecasting. Simulations from AVT-280 were used as test case.
- Nonlinear KLE/PCA of heterogeneous data (geometry and physics) for the dimensionality reduction and reduced order modeling of design spaces was extended to problems of interests within AVT-331.

<u>Task 3:</u>

- An adaptive multi-fidelity metamodel (AMFM) was developed and applied to the CFD-based optimization of a Small Water-plane Area Twin Hull (SWATH) (Pellegrini et al., 2018a) and NACA 0012 and 2412 2D foils (Wackers et al. 2018a,b, Pellegrini et al. 2018b, Quagliarella et al. 2019). Four adaptive sampling techniques were implemented and tested, based on: (1) the maximum prediction uncertainty, (2) a multi-fidelity version of the expected improvement; (3) the maximum prediction uncertainty and the objective function through an aggregated merit factor; and (4) the multi-criteria based on the maximum prediction uncertainty and the objective function. Extensions to hull form performance assessment and optimization were published in a journal paper (Serani et al. 2019d). The research was conducted in collaboration with NATO AVT-252, AVT-331, and AVT-ET-204.
- An adaptive generalized N-fidelity metamodel was developed and applied to a NACA 0012 2D hydrofoil and the 5415 hull form. Methods and results were published in Serani et al. (2019c). This generalization allows for the use of arbitrary levels of fidelities along with the assimilation of simulations and experiments. The research was conducted in collaboration with AVT-331.
- Extensions of adaptive N-fidelity metamodels to noisy data were developed and applied to a NACA 0012 2D hydrofoil, the 5415 hull form, and a ro-pax ferry hull form. Adaptivity of the model allows for adaptive sampling along with the automatic identification of the appropriate degree of interpolation/regression for each fidelity level. The model is also able to characterize the noise associated to different sources/fidelities. Methods and results were published in Wackers et al. (2019a,b) and (2020a,b). The research was conducted in collaboration with AVT-331.
- The adaptive N-fidelity metamodel was extended to regression via Gaussian process (Wackers et al., 2020b). Moreover the N-fidelity metamodel was compared to multi index stochastic collocation (MISC) methods for the solution of UQ problems in naval hydrodynamics, see Tamellini et al., 2020 (in collaboration with AVT-331).
- Combined effects of design-space dimensionality reduction techniques and global optimization algorithms were investigated and the results presented in D'Agostino et al. (2018b). A novel derivative-free optimization algorithm using variable-fidelity/precision evaluations of the objective function was developed and presented in Liuzzi et al. (2019), in collaboration with AVT-331. A hybrid global/local multi-objective method for ship hydrodynamic applications was published in Pellegrini et al. (2020a).
- The use of adaptive surrogate models for multi-fidelity and multi-source information optimization of vehicle design was presented to COMPIT 2020 (Pellegrini et al. 2020b).
- The development, implementation, and application of novel derivative-free optimization algorithms for multi-source information problems (in collaboration with AVT-331) were presented in Liuzzi et al. 2021.

Task 4:

- Applications of interest are documented in the papers listed in the "List of Publications" section, and include: DTMB 5415 and 5415M, a SWATH configuration, a ro-pax ferry, NACA0012 and NACA2412 2D foils, jets in a uniform/stratified environments and propeller wakes.

Training Opportunities

Participation of personnel involved in the project in conferences and workshops:

- UQOP International Conference on Uncertainty Quantification & Optimisation 2020, Brussels, Belgium
- 33rd Symposium on Naval Hydrodynamics 2020, Osaka, Japan
- AIAA Aviation Forum 2019, Dallas, TX, USA
- AIAA Aviation Forum 2020, Virtual Event
- Workshop on Frontiers of Uncertainty Quantification in Fluid Dynamics, FrontUQ19, Pisa, Italy
- 30th European Conference on Operational Research, EURO 2019, Dublin, Ireland
- Postdoc and student seminars at CNR-INM, Rome, Italy
- Student seminars at University of Roma Tre, Rome, Italy

Honors/Awards

1. Dr. Emilio F. Campana and Dr. Matteo Diez were invited speakers at FrontUQ19 Workshop on Frontiers of Uncertainty Quantification in Fluid Dynamics, Pisa, Italy, September 11-13, 2019.
2. Dr. Matteo Diez was invited speaker at the 33rd Symposium on Naval Hydrodynamics, Osaka, Japan, October 18-23, 2020.
3. Dr. Matteo Diez is keynote speaker at the International Conference on Uncertainty Quantification & Optimisation, UQOP2020, Brussels, 17-20 November 2020.
4. Dr. Matteo Diez has been named scientific coordinator of the Multidisciplinary and Robust Optimization section of CNR Virtual Laboratory for Urban Intelligence.
5. Dr. Matteo Diez has served as co-chair for NATO AVT-ET-185 "Goal-driven, multi-fidelity approaches for military vehicle system-level design" (ET, co-chairs: Phil Beran, Matteo Diez)
6. Dr. Matteo Diez is serving as co-chair for NATO AVT-331 "Goal-driven, multi-fidelity approaches for military vehicle system-level design" (RTG, co-chairs: Phil Beran, Matteo Diez)
7. Dr. Matteo Diez is serving as co-chair for NATO AVT-354 "Multi-fidelity methods for military vehicle design" (RWS, co-chairs: Phil Beran, Matteo Diez, Melike Nikbay)
8. Dr. Matteo Diez is serving as co-chair for NATO AVT-ET-204 "Data fusion and assimilation for scientific sensing and computing" (ET, co-chairs: Philippe Bardet, Matteo Diez)
9. Dr. Matteo Diez has joined the Scientific Committee of the VIII International Conference on Computational Methods in Marine Engineering (MARINE 2021), Goteborg, Sweden, May 13-19, 2019.
10. Dr. Matteo Diez has joined the Scientific Committee of the IX International Conference on Computational Methods in Marine Engineering (MARINE 2021), Edinburgh, UK, June 2-4, 2021.
11. Dr. Matteo Diez has joined the Scientific Committee of FrontUQ19 Workshop on Frontiers of Uncertainty Quantification in Fluid Dynamics, Pisa, Italy, September 11-13, 2019.
12. Dr. Matteo Diez and Dr. Andrea Serani have joined the Program Committee of the 4th International Conference on machine Learning, Optimization and Data science (LOD 2018), Volterra, Pisa, Italy, September 13-16, 2018.

13. Dr. Matteo Diez and Dr. Andrea Serani have joined the Program Committee of the 5th International Conference on machine Learning, Optimization and Data science (LOD 2019), Certosa di Pontignano, Siena Italy, September 10-13, 2019.
14. Dr. Matteo Diez and Dr. Andrea Serani have joined the Program Committee of the 6th International Conference on machine Learning, Optimization and Data science (LOD 2020), Certosa di Pontignano, Siena Italy, July 19-22, 2020.
15. Dr. Matteo Diez has joined the Editorial Board of Algorithms (ISSN 1999-4893) in 2019.
16. Dr. Matteo Diez was invited session organizer and chairman at VIII International Congress on Computational Methods in Marine Engineering (MARINE 2019), Goteborg, Sweden, Invited Session on "Multi-fidelity analysis and optimization methods in marine engineering" (organized with Dr. Thomas Fu).
17. Dr. Matteo Diez and Dr. Riccardo Pellegrini were special session organizers and chairmen at the 30th European Conference on Operational Research (EURO 2019), special session on "Derivative-free Optimization: Methods and Applications in Industrial Problems."
18. Dr. Matteo Diez is special session organizer and chairman at the AIAA Aviation 2020 Forum, special session on "Multi-Fidelity Methods for Vehicle Applications" (organized with Dr. Phil Beran and Dr. Laura Mainini).
19. Dr. Matteo Diez is mini-symposium organizer at SIAM Conference on Uncertainty Quantification 2020 (SIAM UQ20). Mini-symposium on "UQ for Complex Fluid Dynamics Problems in Realistic Applications" (organized with Dr. Lorenzo Tamellini and Prof. Maria Vittoria Salvetti).
20. Dr. Andrea Serani was awarded CNR Short Term Mobility Award 2018 with a research project on "High-fidelity Simulations of Ship Performance in Heavy Weather"; host institution: The University of Iowa; host: Prof. Frederick Stern
21. The paper "Augmented Design-Space Exploration by Nonlinear Dimensionality Reduction Methods" by D'Agostino D., Serani A., Campana E.F., Diez M. was candidate to the LOD 2018 Best Paper Award, sponsored by Springer.

Technology Transfer and Interaction with DoD Laboratories

Shape and multi-disciplinary optimization technologies have been transferred to NSWC Carderock Division through a complementary research activity conducted in collaboration with the University of Iowa and NSWCCD, as reported in 2018 and 2020 SNH papers.

List of Publications (journal papers in boldface)

1. Beran, P. S., Bryson, D. E., Thelen, A. S., Diez, M., and Serani, A. (2020) "Comparison of Multi-Fidelity Approaches for Military Vehicle Design," *21th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference (MA&O), AVIATION 2020*, June 15-19.
2. D'Agostino D., Serani A., Diez M., Campana E.F. (2018a) "Deep Autoencoder for On-line Design-Space Dimensionality Reduction in Shape Optimization," *56th AIAA Aerospace Sciences Meeting, SciTech 2018*, Gaylord Palms, Kissimmee, Florida, USA, January 8-12.
3. D'Agostino D., Serani A., Diez M. (2018b) "On the Combined Effect of Design-space Dimensionality Reduction and Optimization Methods on Shape Optimization Efficiency," *19th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference*, Atlanta, USA, June 25-29.
4. D'Agostino D., Serani A., Campana E.F., Diez M. (2018c) "Augmented Design-Space Exploration by Nonlinear Dimensionality Reduction Methods," to be presented at the *4th International Conference on machine Learning, Optimization and Data science - LOD 2018*, Volterra, Italy, September 13-16.

5. **D'Agostino, D., Serani, A. and Diez, M. (2020a) "Design-space assessment and dimensionality reduction: An off-line method for shape reparameterization in simulation-based optimization,"** ***Ocean Engineering*****, 197, p.106852.**

6. D'Agostino D., Andre M., Bardet P., Serani A., Felli M., and Diez M. (2020b) "Observing PIV Measurements Through the Lens of Data Clustering," *33rd Symposium on Naval Hydrodynamics*, Osaka, Japan, 31 May - 5 June.

7. Diez, M., Volpi, S., Serani, A., Stern, F. and Campana, E.F. (2018) "Simulation-Based Design Optimization by Sequential Multi-criterion Adaptive Sampling and Dynamic Radial Basis," in *Advances in Evolutionary and Deterministic Methods for Design, Optimization and Control in Engineering and Sciences*, 48, p.213.

8. **Durante, D., Broglia, R., Diez, M., Olivieri, A., Campana, E.F. and Stern, F. (2020) "Accurate experimental benchmark study of a catamaran in regular and irregular head waves including uncertainty quantification,"** ***Ocean Engineering*****, 195, p.106685.**

9. Khan S., Serani A., Diez M., Kaklis P. (2021) "Physics-Informed Feature-to-Feature Learning for Design-Space Dimensionality Reduction in Shape Optimisation," submitted to *AIAA SciTech 2021 Forum*, Nashville, TN, USA, January 11-15.

10. Liuzzi G., Lucidi S., Rinaldi F., Pellegrini R., Serani A., D'Agostino D., and Diez M., (2019) "Derivative-free line-search algorithm for variable-accuracy optimization," *30th European Conference on Operational Research (EURO 2019)*, 23rd - 26th June, Dublin, Ireland, 2019.

11. Liuzzi, G., Lucidi, S., Rinaldi, F., Pellegrini, R., Serani, A., and Diez, M. (2020) "Derivative-Free Line-search Algorithm for Variable-Fidelity Optimization," *21th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference (MA&O), AVIATION 2020*, Oral Presentation, June 15-19.

12. Liuzzi, G., Lucidi, S., Rinaldi, F., Pellegrini, R., Serani, A., and Diez, M. (2021) "Derivative-Free Line-Search Algorithm for Multi-Information-Source Optimization," submitted to *AIAA SciTech 2021 Forum*, Nashville, TN, USA, January 11-15.

13. Pellegrini R., Serani A., Broglia R., Diez M., Harries S. (2018a) "Resistance and Payload Optimization of a Sea Vehicle by Multi-Fidelity Surrogate Models," *56th AIAA Aerospace Sciences Meeting, SciTech 2018*, Gaylord Palms, Kissimmee, Florida, USA, January 8-12.

14. Pellegrini R., Serani A., Diez M., Wackers J., Queutey P., Visonneau M. (2018b) "Adaptive Sampling Criteria for Multi-fidelity Metamodels in CFD-based Shape Optimization," *7th European Conference on Computational Fluid Dynamics (ECFD 7)*, Glasgow, UK, June 11-15.

15. **Pellegrini, R., Serani, A., Liuzzi, G., Rinaldi, F., Lucidi, S., Diez, M. (2020a) "Hybridization of Multi-Objective Deterministic Particle Swarm with Derivative-Free Local Searches,"** ***Mathematics*****, Volume 8, 546.**

16. Pellegrini R., Serani A., Ficini S., Broglia R., Diez M, Wackers J., Visonneau M., (2020b) "Adapt, Adapt, Adapt: Recent Trends in Multi-fidelity Digital Modelling for Marine Engineering," 19th Conference on Computer Applications and Information Technology in the Maritime Industries COMPIT'20, Pontignano, Italy, 17-19 August.

17. Piazzola, C., Tamellini L., Serani, A., Broglia, R., Pellegrini, R., and Diez, M. (2020) "Uncertainty Quantification of Ship Resistance via Multi-Index Stochastic Collocation and Radial Basis Function Surrogates: A Comparison," *21th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference (MA&O), AVIATION 2020*, June 15-19.

18. Quagliarella, D., Serani, A., Diez, M., Pisaroni, M., Leyland, P., Montagliani, L., Iemma, U., Gaul, N.J., Shin, J., Wunsch, D. and Hirsch, C. (2019) "Benchmarking Uncertainty Quantification Methods Using the NACA 2412 Airfoil with Geometrical and Operational Uncertainties," *AIAA Aviation 2019 Forum* (p. 3555), Dallas, TX, USA.

19. Quagliarella D., Diez M., Pisaroni M., Leyland P., Iemma U., Hirsch C., Wunsch D., Stern F., “NATO AVT-252 Stochastic Design Optimization for Naval and Aero Military Vehicles – Final Report,” STO-TR-AVT-252, 2019, Chapter 2: “Overview of UQ and Stochastic Optimization Methodologies”

20. Quagliarella D., Serani A., Diez M., Pisaroni M., Leyland P., Montagliani L., Iemma U., Gaul N.J., Wunsch D., Hirsch C., Stern F., “NATO AVT-252 Stochastic Design Optimization for Naval and Aero Military Vehicles – Final Report,” STO-TR-AVT-252, 2019, Chapter 11: “Benchmarking UQ Methods Solving NACA-2412 Airfoil Problems”

21. Quagliarella D. and Diez M. (2020) “An Open-Source Aerodynamic Framework for Benchmarking Multi-Fidelity Methods,” *21th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference (MA&O), AVIATION 2020*, June 15-19.

22. Serani A. and Diez M., (2018). “Shape Optimization under Stochastic Conditions by Design-space Augmented Dimensionality Reduction”, *19th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference*, Atlanta, USA, June 25-29.

23. Serani A., D’Agostino D., Campana E.F., Diez M. (2018). “Assessing the Interplay of Shape and Physical Parameters by Nonlinear Dimensionality Reduction Methods,” *32nd Symposium on Naval Hydrodynamics*, Hamburg, Germany, August 5-10

24. Serani, A., Durante, D., Diez, M., D'Agostino, D., Clement, S., Badra, J., Andre, M., Habukawa, M. and Bardet, P. (2019a) “PIV data clustering of a buoyant jet in a stratified environment,” *AIAA Scitech 2019 Forum* (p. 1830), San Diego, CA, USA.

25. Serani, A., Diez, M., Wackers, J., Visonneau, M. and Stern, F. (2019b) “Stochastic Shape Optimization via Design-Space Augmented Dimensionality Reduction and RANS Computations,” *AIAA Scitech 2019 Forum* (p. 2218), San Diego, CA, USA.

26. Serani, A., Pellegrini, R., Broglia, R., Wackers, J., Visonneau, M. and Diez, M., (2019c) “An Adaptive N-Fidelity Metamodel for Design and Operational-Uncertainty Space Exploration of Complex Industrial Problems, *VIII International Conference on Computational Methods in Marine Engineering, MARINE 2019*, Goteborg, Sweden.

27. **Serani, A., Pellegrini, R., Wackers, J., Jeanson, C.E., Queutey, P., Visonneau, M. and Diez, M. (2019d) Adaptive multi-fidelity sampling for CFD-based optimisation via radial basis function metamodels, *International Journal of Computational Fluid Dynamics*, 33:6-7, 237-255, DOI: 10.1080/10618562.2019.1683164**

28. **Serani, A., D’Agostino, D., Campana, E.F. and Diez, M. (2019e) “Assessing the Interplay of Shape and Physical Parameters by Unsupervised Nonlinear Dimensionality Reduction Methods,” *Journal of Ship Research*, DOI: https://doi.org/10.5957/JOSR.09180056.**

29. Serani A., Diez M., Campana E.F., Stern F., “NATO AVT-252 Stochastic Design Optimization for Naval and Aero Military Vehicles – Final Report,” STO-TR-AVT-252, 2019, Chapter 7: “Reliability-Based Robust Hull-Form Optimization of a Naval Destroyer in Waves”

30. Wackers J., Queutey P., Visonneau M., Pellegrini R., Serani A., Diez M. (2018a) “CFD-Based Shape Optimization Under Limited Computational Resources: A Study on Adaptive Multi-Fidelity Metamodeling”, *17th International Conference on Computer Applications and Information Technology in the Maritime Industries, COMPIT 2018*, Pavone, Italy, May 14-16.

31. Wackers J, Jeanson C.-E., Queutey P., Visonneau M., Pellegrini R., Serani A., Diez M. (2081b) “Hull shape optimisation using multi-fidelity metamodels and adaptive grid refinement,” *21st Numerical Towing Tank Symposium, NuTTS 2018*, Cortona, Italy, September 30 – October 2.

32. Wackers, J., Serani, A., Pellegrini, R., Diez, M. and Visonneau, M. (2019a) “Adaptive multifidelity shape optimization based on noisy CFD data.” *International Conference on Adaptive Modeling and Simulation, ADMOS 2019*, Alicante, Spain.

33. Wackers J., Visonneau M., Serani A., Pellegrini R., Broglia R., and Diez M. (2019b) "Uncertainty quantification by adaptive multifidelity surrogates of noisy CFD data," *FrontUQ19, Workshop on Frontiers of Uncertainty Quantification in Fluid Dynamics,* Pisa (Italy), 11-13 September.

34. Wackers J., Visonneau M., Serani A., Pellegrini R., Broglia R., and Diez M. (2020a) "Multi-Fidelity Machine Learning from Adaptive- and Multi-Grid RANS Simulations," *33rd Symposium on Naval Hydrodynamics*, Osaka, Japan, 31 May - 5 June.

35. Wackers, J., Visonneau, M., Ficini, S., Pellegrini, R., Serani, A., and Diez., M., (2020b) "Adaptive N-Fidelity Metamodels for Noisy CFD Data," *21th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference (MA&O), AVIATION 2020*, June 15-19.

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