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Data Based Proposal for a Hydrodynamic Ship Model Testing Facility in the Arab Region

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1. ABSTRACT: This research aims to review current challenges with regard to enhancing Arab ship design and building capabilities, with focus on how to be a smart buyer, and provide insights towards sustainable shipbuilding industry with quality. This requires an understanding of both what is needed and what can be achieved together with a process that allows this to be done as efficiently as possible. The objectives of the project are to research hydrodynamic facilities as a whole and their particular utilisation from a maritime security perspective. Links between similar projects in other maritime maritime sectors shall be drawn to construct a benchmark for the desired hydrodynamic facility outputs and vessel categorizations for the Arab maritime sector's vision 2023 – 2050. The proposed process philosophy addresses part of the problem, i.e. matching needs, quality and affordable ships. The solutions are concluded from a total of 46 hours of recorded interview data that was gathered and fine- tuned. Common denominators were drawn between the answer categories and a total of 17 responses were the key areas that the participants made note of were analysed and postprocessed according to the order of importance for the responses in the questionnaire. These participants ranged from past, current and upcoming mid-level up to leaderships at their organisations oriented with the strategic planning and the technical restructuring of the fleet to adhere to the projected technical and operational challenges in sea going operations for the next 30 years. A conclusion of the findings guided the study towards the need of advancing the hydrodynamic facilities in the Arab World with a proposed design of a towing tank and thorough business plan for the decision makers to consider.

Keywords: *Smart Ship Buyer, Ship hydrodynamics, Towing tank, Ship design, Shipbuilding.*

2. INTRODUCTION

United Nations Conference on Trade and Development (UNCTAD) has reported a growth in the global merchant fleet by 63 million dwt in January 2022 when compared with previous year. The current total carrying capacity by the world merchant fleet has reached 2.2 billion DWT, with Greece at the top of the market share holding 18%, followed by China with 13%, Japan 11%, while Singapore and Hong-Kong with 6% and 5% respectively, i.e. half of the world's tonnage is owned by Asian companies and approximately 39% is owned by European owners. This increase in the demand of efficient vessels would shedlight on the opportunities for developing nations to enhance their economic growth through investing in the blue economy and building competitive ships.

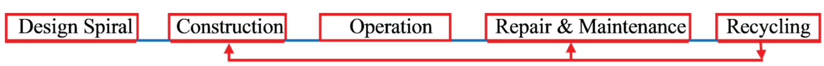

Fig. 1: Stages of ship life cycle.

This paper aims to address the capability of the Arab world in designing and building efficient ships, as such the work is focused on key elements influencing shipbuilding industry, such as research hydrodynamic facilities as a whole and their particular utilisation from a maritime industry perspective. Links between similar projects in other maritime sectors shall be drawn to construct a benchmark for the desired hydrodynamic facility outputs and vessel categorizations for the Arab maritime industry sector's vision 2020 – 2050.

Although. limited hydrodynamic facilities recently constructed and installed in the Arab region, such as in 2019, the Military Technical college in Cairo installed a towing tank that features 8x700mm hinge depth absorbing flaps in a 50m long tank with a towing carriage able to run along the full length of the tank. Following the MTC's tank the Khalifa University Center for Robotics and Autonomous Systems was established in 2021 to conduct pioneering research in robotics relevant to industry and society. The tank features 32×1.8m paddles in a double ended arrangement. 12 flow ducts provide flow across the width of the tank. The tank is 8m wide x 18m long x 3m deep (Edinburgh Designs, 2023). The Arab region has potential to compete with the global market in designing and building region's need of commercial vessels, if adequate hydrodynamic facilities exist, e.g. wave basins, bigger towing tanks (Rakesh, 2019) and (Day et. al, 2015), and cavitation tunnels (Terwisga. 2007) and (Brandner et al., 2007)

This research will focus on investigating challenges in designing and building efficient non- SOLAS vessels, i.e. vessels < 400 GT, such as tug boats, offshore supply vessels, fishing boats, yachts, RO-PAX ferries, and high-speed patrol boats. Most of the mentioned vessels are designed by overseas partners and some of them are built by Arab shipyards. However, such proven hull vessels are not amended to particularly suit the zone areas where they are going to operate, as such this paper is a step forward towards owning an Arab hydrodynamic facility by detailing the design of a proposed towing tank and by providing decision makers with business plan and expected expenses.

3. METHODOLOGY

In order to construct the optimal path four phases methodology was applied as shown in Fig. 2.

The research methodology implied to achieve the research objectives were broken into 4 phases as follows:

Phase 1: An introduction explaining the Arab region's coastal operation parameters, literature review and the research questions. In addition, an identification of suitable organisations and specialists to contact during the questionnaire phases.

Phase 2: Questionnaire for group "A", i.e. maritime experts, policing and users and group "B" for hydrodynamic research providers and managers.

Phase 3: Analysis of the findings for phase 2

Phase 4: Developing the required hydrodynamic capabilities and parameters.

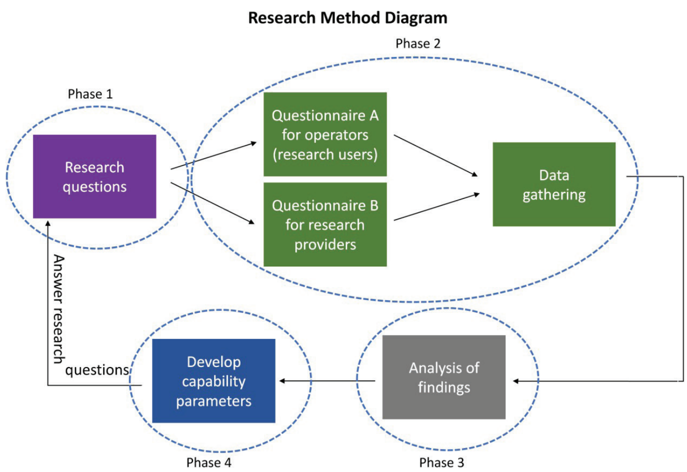

Fig. 2: Diagram showing the research method approach devised to reach research question objectives.

3.1. Questionnaire Set-up

Outcome of the questionnaire of group A, i.e. that was directed towards maritime industry, policing and users. A total of 23 current and past members of the maritime industry were interviewed. These participants ranged from past, current and upcoming leaderships at their maritime organisations oriented with the strategic planning and the technical restructuring of the fleet to adhere to the projected technical and operational challenges in sea going operations for the next 27 years. Three interviews were also conducted with hydrodynamic facility directors/ managers. A total of 46 hours of recorded interview data was gathered and fine tuning was arranged. Common denominators were drawn between the answer categories and a total of 17 responses were the key areas that the participants made note of were placed in a graph to show the order of importance for the responses in the questionnaire as shown in table 1.

Fig. 3 presents a summary bar graph that was drawn to arrange the 17 responses N1-N17 and show an effective representation on the importance of each highlighted ability category mentioned in the interviews.

Table 1: Showing key capabilities within the shipbuilding industry:

Response#	*Capability Highlighted*
N1	optimization balance between budgets and needs
N2	the ability to independently differentiate between the presented hulls during tendering
N3	model and computational testing assessment for those hulls during various conditions needs to be conducted to understand the full scope of how these hulls perform
N4	ability to understand the effects of the varying mission speeds on the hulls performance in calm waters and waters up to sea state 3.
N5	in house computation assessments to understand the performance nature and the performance loads on the operation
N6	assess how a particular hull would perform if the nature of the loads required have not been incorporated in a previous design and to ensure that these changes will yield optimal results
N7	To have accurate performance and sea keeping data presented on charts to compare how the hull would perform if it was to be made out of various metals or GRP, in order to ensure which path to take with the hull material and conduct inhouse assessments of such hull factors.
N8	The ability to compare various hull data from various shipyards during tendering and make selection based on the hull performance data and be able to analyses it
N9	Better understanding of mission roles
N10	The ability to translate mission profiles into hulls and designs that achieve the required performance in terms of operational speeds, seakeeping and withstanding loads
N11	The ability to differentiate between various designs and compare the operation nature in waters from 3 – 50 metres in depth
N12	The possibility to enhance existing hulls and assess performance and operation based on those weight increase enhancements (installing armoring plates which adds 30-40% to the hulls weight
N13	Ability to distinguish between scrapping, upgrading and refitting existing hulls from feasibility perspective
N14	The ability to redistribute weights, systems, engines and change propulsion packages and ensure that these fittings do not negatively affect the hulls operation speeds and sea keeping
N15	ensure that slow speed stability and sudden loads at one side of the boat for boarding missions does not sacrifice the safety of the mission
N16	Third party auditing and aid in elevating operational and engineering parameters (consultations)
N17	Collision and ramming impact on vessel hulls for intended or accidental impacts during operation assessments

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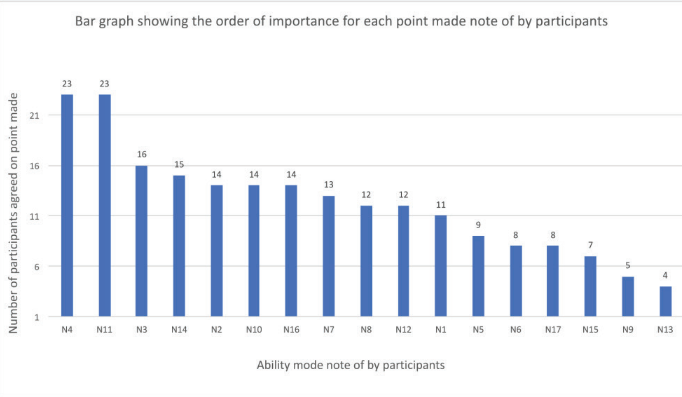

Fig. 3: A bar graph showing effective representation on the importance of each highlighted ability category mentioned in the interviews.

The answers for the questionnaire along with the overall operation requirements were assessed for the given vessels' categories. Similarities were drawn between the various responses given by these specialists and a conclusion of the findings guided the study towards three components.

A lot of towing tanks all over the world get enhanced to deal with developing and studying large waves hance large wave making capacity, however, the maximum projected sea state within the given parameters of the assessment was sea state 3, and the general recommendation was to build the facility to a sea state 4 wave making capability since future hull developments might require operation in areas of the Mediterranean sea, Red sea and the Arabian Gulf with normal sea states reaching 3.5. The towing tank length proposed in these interviews was 100 to 200 meters in length, a width of 4 to 6 meters, a depth of 3 meters and with a carriage speed of 4 to 7+ m/s. Even if the outcomes of the questionnaire were focused on shallow territorial waters, a 3-metre towing tank assumption was suggested to reach a low Froude depth number during high speeds.

4. RESULTS

The ability to assess the hydrodynamic performance of a range of vessels that can operate at relatively high speeds up to 40 knots and in relatively low sea states (Arab's coastal region). Due to the relatively short vessel lengths and high-end speed capability (resulting in very high length Froude numbers, which is speed/length ratio and could provide corresponding ship models' speed to a known full-scale hull), it is concluded that such a capability must include both experimental and numerical components.

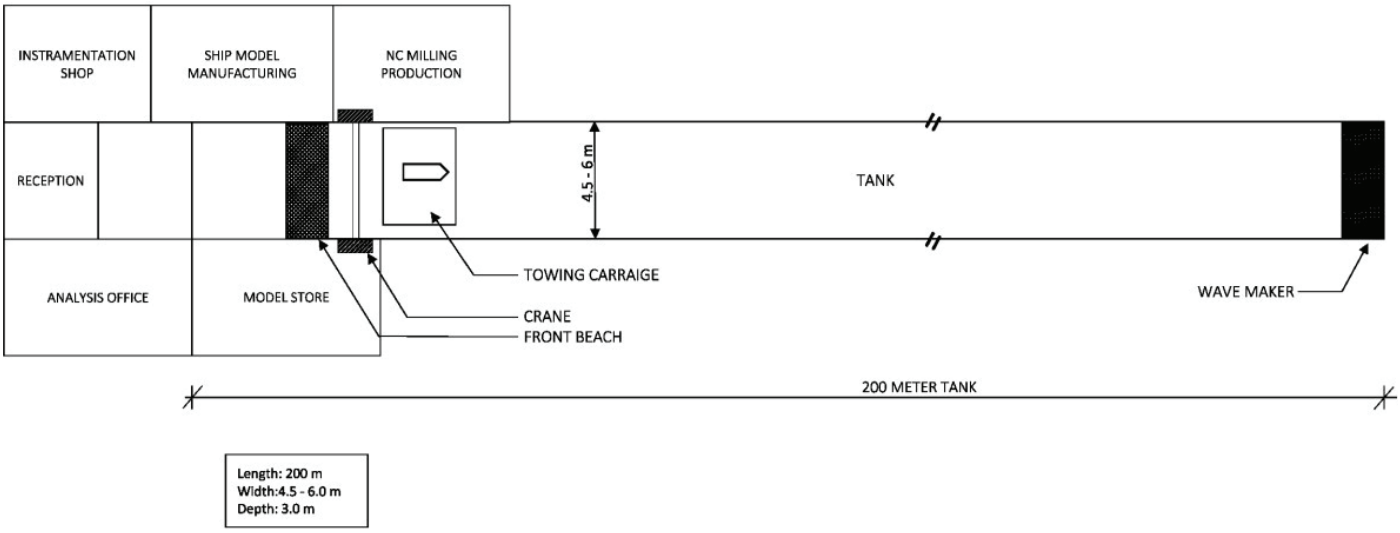

Fig. 4: Projected general layout of the Arab's hydrodynamic facility.

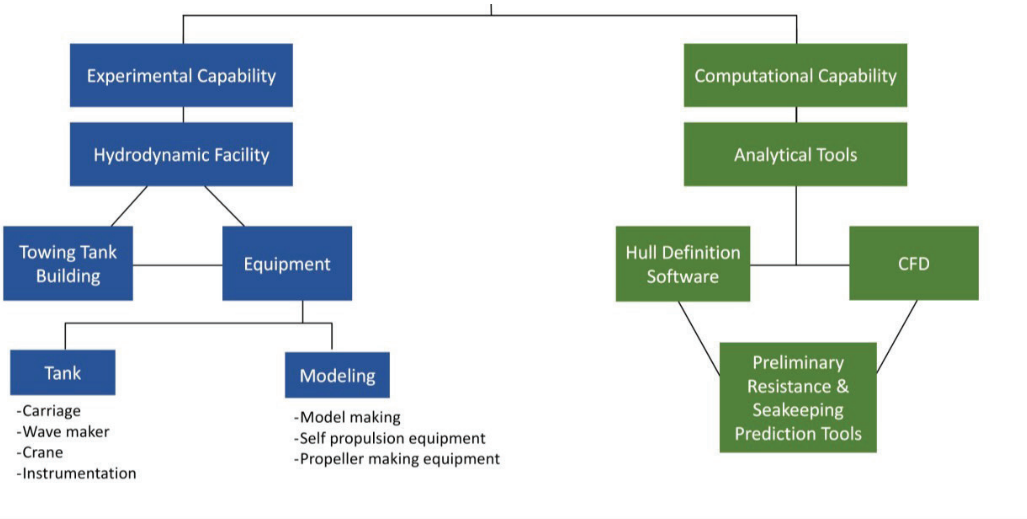

Fig. 5: Breakdown of the Key Facility, equipment, and analytical tool components to develop a hydrodynamic capability.

Such operations are considered to be generally beyond the level of confidence currently provided by numerical methods alone. Thus, it is highly recommended that a dedicated experimental facility, in the form of a high-speed towing tank, become the 'flagship' of the hydrodynamic capability. Based on the outcomes of questionnaires to groups A and B, a required facility with the following parameters are shown in Fig. 4.

As part of the study, a review of a large number of existing Towing Tanks was performed. This was aided by a list of such facilities compiled by the International Towing Tank Conference (ITTC, 2017). It was found that only a small percentage of existing facilities were geared to handle the high speed and/or small craft that is the focus of this study, as an added capability to the Arab's navies to design and build their own high-speed patrol boats. Further investigations involved direct discussions with staff from existing Towing Tank facilities (Turnock, 2017; Macfarlane, 2017) and providers of key equipment (Ross, 2017; Tiedeman, 2017). Following this investigation and discussions it is recommended that a Towing Tank of the approximate dimensions shown in Fig. 4 be developed, with key facility equipment and analytical components as shown in Fig. 5. Since the recommended facility is assumed to be built in a governmental agency, land around the towing tank will be government owned; hence, no need to incorporate land purchase costs into the assessment. The required numerical and experimental tools with updated pricing are summarised in Tables 2 and 3.

Table 2: Hydrodynamic Essential Numerical Tools:

Analytical Tool	*Example*	*Price Range (USD)*	*Yearly renewal Fees (USD)*
CFD	**STAR CCM+**	20,000	20,000
Hull definition software, including preliminary resistance and seakeeping predictions tools	MAXSURF	8,800	8,800
Preliminary resistance and seakeeping prediction tools	MAXSURF	1,500 to 3,500	1,500

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Table 3: Hydrodynamic Essential Experimental Tools:

Category	*Component*	*Description*	*Pricing Range*
Towing tank	**Carriage**	Fully installed hydrodynamic laboratory ship model testing carriage for a towing tank 6m in width and 200 m in length. Speeds up to 12 m/s and max acceleration and deceleration :1 m/s² Emergency braking deceleration: 3 m/s² Carriage control system and operators test station that are designed for mounting various dynos and instrumentation.	1.66 to 2.7 million USD
	Rails	Fully installed 200 metre rails for high speed carriage with alignment and levelling sleepers, buffers and braking system and rail gauge (centre between rails): 6.8 m	1.26 to 2.14 million USD
	Resistance Dynamometer	Resistance dynamometer and pneumatically operated model clamp for measuring the resistance of ship models which are being towed by carriage. Also used during propulsion tests with ship models for applying force in addition to the propeller thrust when required. The ship model is towed by way of a coupling rod which can freely adjust in 3 planes. The transducer range rated load is 100 to 500N that includes a resistance dynamometer for the measurement of resistance and alteration of draught and trim during tests of relatively small ship models of up to 3m on smooth water and in waves. Stainless Steel Towpost suitable for larger models upto 5m in length and Calibration Devices excluding weights. Guiding arms and equipment designed for the measurement of changes to Trim / Draught of ship models during resistance and propulsion tests.	390,000 to 660,000 USD
	Open-water propeller dynamometer	Electric open water dynamometer for use in towing tanks with streamlined watertight casing to standard height 630mm for use in ship model towing tanks. Equipped with support tube and equipment for measuring the traverse forces action on the bearing at the shaft end of the shaft. Is to also include stern tubes and extra weights.	250,000 to 425,000 USD
	Ship model Self propulsion dynamometer	Ship model Propeller Dynamometer for carrying out propulsion tests with ship models of a wide range of sizes. Rated Max Torque ±10Nm, Rated max Thrust ±250N at 3500rpm. Ship model Propeller Dynamometer for carrying out propulsion tests with ship models of a wide range of sizes. Rated Max Torque ±4Nm, Rated max Thrust ±100N at 3500rpm. Equipped with elastic coupling with support, shafts and bearings and stern tube assembly support brackets and static calibration device.	70,000 to 120,000 USD
	Self Propulsion Drive System	Self propulsion drive system with drive shafts and mounting kits. AC Self-propulsion drive motor with model mounting brackets, integrated encoder for speed feedback control. Type: AC Brushless Servo Motor.	60,000 to 100,000 USD
	Wave maker	Fully installed wet back hinged flap type irregular wave maker generating waves 300 mm high and frequency of wave 0.5 – 5 seconds.	420,000 to 720,000 USD
	Crane	12 metre extension arm pal finger 4 ton knuckle boom crane.	50,000 to 100,000 USD
	Beaches	6 m parabolic wave absorbing beach with movable centre.	165,000 to 280,000 USD

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Modelling Equipment	**Ship Models**	Various vessel and hull models ranging 2 – 4 m in length with single screw and twin screw propeller shafts.	130,000 to 220,000 USD
	Propeller models	5 model propellers suitable for use with the ship models.	90,000 to 150,000 USD
	Model making, Propeller making	Various technical workshop model making machinery and tools including a numeric control model making machine and consumables	350,000 to 700,000 USD
	Self-propulsion	Self propulsion drive system, with drive motors, drive motor speed encoder rack and counter, drive shafts, cabling and drive system control.	60,000 to 100,000 USD
FINAL BUDGETARY ESTIMATION RANGE FOR EXPERIMENTAL TOOLS			**4,955,000 TO 8,423,500 USD**

Specialities and experiences vary when structuring the required staff to operate a hydrodynamic facility. A breakdown of the typical staff required to develop the hydrodynamic capability can be seen in Fig. 6.

To operate a hydrodynamic facility various roles and specialties with varying salary ranges are required to achieve the desired experimentation and analysis investigations required to elevate fleet hydrodynamic capability. Table 4 shows the breakdown of the required staff based on minimum number required per specialty and the yearly salary range per specially.

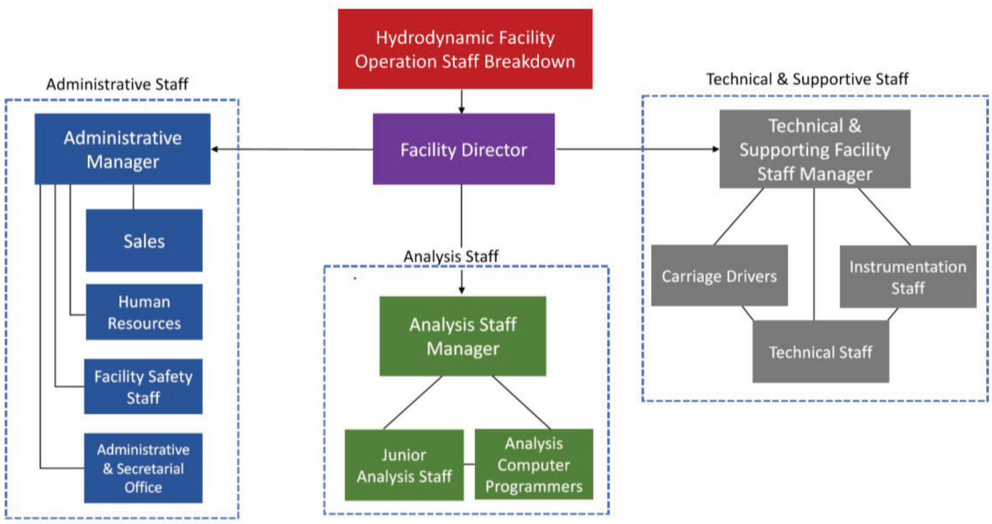

Fig. 6: Hydrodynamic facility staff breakdown.

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Table 4: Summary of the required staff and corresponding budget to operate a towing tank:

Department	Specialty / Job title	Number required	Yearly salary range per member (USD)	Yearly salary range per team (USD)
Director	Facility Director	1	210,000 – 275,000	
	Analysis Staff Manager	1	150,000 – 210,000	
Analysis Staff	Junior Analysis Staff	3	150,000 – 210,000	450,000 – 630,000
	Analysis Computer Programmer	2	150,000 –210,000	300,000 – 420,000
	Technical & Supporting Facility Staff Manager	1	150,000 – 210,000	
Technical & Supporting Staff	Carriage Drivers	2	120,000 – 150,000	240,000 – 300,000
	Technical Staff	2	120,000 – 150,000	120,000 – 150,000
	Instrumentation Staff	2	120,000 – 150,000	120,000 – 150,000

The varying experience and skill levels required to construct the hydrodynamic facility operation staff can be better explained in table 5. A percentage representation of the staff operation costs percentage to operate the hydrodynamic capability as per specialty is shown in Fig. 7.

Table 5: A brief of hydrodynamic facility departments, staff roles, numbers and salary ranges:

Department	Role	Role Description
Director	• Facility Director	A highly experienced hydrodynamicist with 20 – 30 years experience in managing hydrodynamic facilities. At the beginning of the project He will be acting as a consultant to setup and establish the procurement parameters for the tender and will be working on recruiting staff and leading the team. A person with vast knowledge in defence projects and costal operation security projects for vessels meeting parameters of table 1.
R & D	• Analysis Staff Manager	A Ph.D. senior staff analysis manager with 10 – 15 years' experience in managing and conducting analysis. Will be recruited by the facility director.
	• Junior Analysis Staff	Three junior staff that hold a naval architecture and/or marine engineering degrees with 5 years experience in CFD, STAR CCM, MAXSURF and other analysis software. At later stages these staff will be replaced by the Arab Ph.D holders upon finishing training and being incorporated into to operation of the facility.
	• Analysis Computer Programmer	Two computer programmers with 5 years experience to conduct basic codding are to be recruited and incorporated into the analytical staff by the facility manager towards the end of the 4th year of the project.

Technical & supporting staff	• Technical & Supporting Facility Staff Manager	A professional staff member with an Masters degree and a minimum of 15 years experience in conducting supporting facility tasks to the towing tank. He will be in charge of fitting the machinery and carrying handover training for Arab professional staff recruits to operate the facility.
	• Carriage Drivers	Two carriage drivers to be recruited by facility director.
	• Technical Staff	Two technical staff to conduct modelling and modifications to models. At later stages the technical staff manager will train and handover modelling tasks to Arab nationals to conduct these tasks.
	• Instrumentation Staff	Two instrumentation staff that conduct maintain of equipment. Arab instrumentation staff member can conduct that task whilst supervising maintenance by third party outsourced contract at later stages.

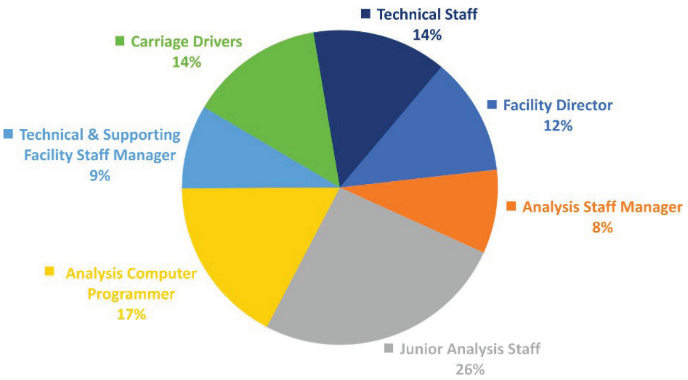

Fig. 7: Chart showing the Staff operation Cost Percentage per Specialty relative to the projected yearly staff operation cost range 1,600,000 – 2,100,000 USD.

Due to factors such as currency differences, inflation due to duration of project and variation in the Arab's countries tendering process, the overall project parameters were all multiplied by a factor of

2.5. This is because the overall parameters of the projected operating and installation costs might encounter increases; hence the standard tendering practice to build the budgets with a multiplication factor of 2.5 to the estimated costs of all areas as shown in table 6. As can be seen the projected building cost is expected to range from 7 to 12 million USD. The experimentation tools cost is expected to range from 4.955 to 8.432 million, while the annual operating costs, including staff and ongoing equipment maintenance and licencing cost, is expected to be in the order of 1.6 to 2.1 million USD and 51,500 to 83,500 USD respectively. As noted, this incorporate any other expenses to optimize the facility operation parameters.

Other factors such as additional supportive staff, travel, conferences, maintenance costs or the deviations of recruiting of various operation staff have not been included since they are not significant to the change in the overall pricing margin and acquainted for with the 2.5 multiplying factor for deviations. Training costs for personnel to obtain PhD over a 4 year period was also not looked into. After studying the various parameters of developing the hydrodynamic capability and its key components, an implementation plan was drawn over 5 years projected period, as presented in Table 7.

The first step in developing the ability is to begin by 6 months recruiting and hiring period, for the facility manager who will also act as a consultant. The manager will employ staff to aid in constructing the tender and tailoring the procurement process over the next 6 months.

Table 6: Projected Final Installation and Operation Costs

Category		Projected Price Range (USD)	Price range X 2.5 factor	Comments
Construction	**Land**	The land value factor was not accounted for in this study.		
	Building	7 - 12 million	17.5 - 30 million	The building price varies based on labour cost and material costs, however an average estimation was calculated, as per the international market and reviewers' feedback.
Equipment	**Experimental Tools**	4,955,000 - 8,423,500	Both the experimentation and analysis tools were calculated with the projected yearly increase of price data (inflation rate) and expected increase range of price; hence, these components of the study were not accounted for in the 2.5 factor.	
	Analysis tools	51,500 - 83,500		
Projected Final Installation Cost			**22.5 – 38.5 million USD**	
Projected final yearly staff and operation cost once facility is fully operational			**1.6 – 2.1 million USD**	

Table 7: Projected budget 2023 - 2028

Year	Projected Budget Breakdown (USD)		Overall Yearly Budget Projection (USD)
2023	6 months facility director salary	110,000 – 137,500	110,000 – 137,500
2024	12 months facility director salary	210,000 – 275,000	6,960,000 – 11,825,000
	30% payment of tender	6,750,000 – 11,550,000	
2025	12 months facility director salary	210,000 – 275,000	210,000 – 275,000
2026	12 months facility director salary	210,000 – 275,000	510,000 – 695,000
	12 months analysis manager salary	150,000 – 210,000	
	12 months technical manager salary	150,000 – 210,000	
2027	Full Staff salary	1,600,000 – 2,100,000	1,600,000 – 2,100,000
2028	Full Staff Salary	1,600,000 – 2,100,000	17,350,000 – 29,050,000
	70% Final payment	15,750,000-26,950,000	

By the beginning of the second year a tender could be issued for a 6-month period and shall be an all-inclusive tender to build the facility and install all required components within a 30-month period. Software and electronic components of the tender could be delayed till the last part of the installation process to ensure that by the handover period the components did not age. During the first 6 months of the implementation plan a total of 2 – 4 hydrodynamic PhD students, either civilians or members of the Arab natives get sent to conduct PhD studied/ training to enable them to be incorporated into the facility operation within the 4th and 5th years of implementation. Towards the end of the third year and for a 12-month period the analysis staff manager will be recruited and will go on to recruit the operational staff.

A technical staff then could be recruited towards the last year of the implementation and will conduct assessments on available technical staff available and train them in the required tasks. The last 12 months of the implementation plan will involve trial operation and handover training from the contracting party. Based on the proposed hydrodynamic capability implementation plan, a yearly breakdown of the budget between 2023 – 2028 is calculated.

5. CONCLUSIONS

In conclusion, the data gathered and analysed from the qualitative questionnaire provides necessary information to identify the key parameters required to elevate the Arab's hydrodynamic capabilities as the fleet would significantly increase throughout the coming decades. The need for elevating the Arab maritime sector's hydrodynamic capabilities has been identified by the assessment and findings of this paper. The ability to assess the hydrodynamic performance for a range of vessels that operate at relatively medium to high speed up to 40 knots and in relatively low sea states (from calm water up to the top of sea state 3) generated the capability design parameter.

Based on the outcome of the interviews conducted and the assessment of the data findings, the key abilities, parameters and technical requirements to develop the required hydrodynamic capability were investigated. The experimental capability should be complemented by a numerical capability. It is estimated that the total cost to develop and implement this capability is 22.5 to 38.5 million USD, followed by an annual projected operational cost (once facility is fully operational) of 1.6 – 2.1 million USD.

A yearly projected operation projected final yearly staff and salary cost once facility is fully operational of 1.6 – 2.1 million USD is estimated.

A 5-year plan to implement the parameters of this capability along with its, components, and operation staff will enable the Arab countries and the region to enhance its projected fleet outlook for the upcoming operational challenges in its future.

6. FURTHER WORK

A feasibility study addressing financial analysis and market attractiveness assessments and a towing tank operation competition study can be conducted if the hydrodynamic facility will operate for profits to overlap defence and commercial operations.

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