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PI/PD Name: Peter A Jumars

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☒ White

Disability Status:
(Select one or more)
☐ Hearing Impairment
☐ Visual Impairment
☐ Mobility/Orthopedic Impairment
☐ Other
☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

Ethnicity Definition:
Hispanic or Latino. A person of Mexican, Puerto Rican, Cuban, South or Central American, or other Spanish culture or origin, regardless of race.
Race Definitions:
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Black or African American. A person having origins in any of the black racial groups of Africa.
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PI/PD Name: Lee Karp-Boss

Gender: ☐ Male ☒ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☐ White

Disability Status:
(Select one or more)
☐ Hearing Impairment
☐ Visual Impairment
☐ Mobility/Orthopedic Impairment
☐ Other
☐ None

Citizenship: (Choose one) ☐ U.S. Citizen ☐ Permanent Resident ☒ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

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PI/PD Name: Daniel Grunbaum

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☒

REQUIRED: Check here if you are currently serving (or have previously served) as a PI, co-PI or PD on any federally funded project ☒

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PI/PD Name: James J Riley

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race: (Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status: (Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: Steve T Wereley

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☒ White

Disability Status:
(Select one or more)
☐ Hearing Impairment
☐ Visual Impairment
☐ Mobility/Orthopedic Impairment
☐ Other
☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:

Sent by e-mail to Phil Taylor and Dave Garrison, Biological Oceanography

REVIEWERS NOT TO INCLUDE:

We respectfully request that this proposal not be sent to Ulf Riebesell of the Alfred Wegener Institute in Bremen, Germany. Jumars accused him of using preprints from then-students Paul Hill and Lee Karp-Boss without acknowledgment, and there is reason to expect residual hard feelings as well as fear on our part of his potential use of proposal ideas. If you use Victor Smetacek as a reviewer, please emphasize that the information contained is priveledged and not to be communicated to others at his laboratory (i.e., Riebesell).

List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 02-2	FOR NSF USE ONLY
NSF 01-2	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) OCE - BIOLOGICAL OCEANOGRAPHY	0219773

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				186875787	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)
016000769		

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
University of Maine	University of Maine 5717 Corbett Hall Orono, ME. 044695717
AWARDEE ORGANIZATION CODE (IF KNOWN) 0020537000	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply)
(See GPG II.C For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **Collaborative Proposal: Form and function of phytoplankton in unsteady, low Reynolds-number flows**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ 405,072	36 months	09/01/02	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
- ☐ BEGINNING INVESTIGATOR (GPG I.A)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.6)
- ☐ HISTORIC PLACES (GPG II.C.9)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.C.11)
- ☐ VERTEBRATE ANIMALS (GPG II.C.11) IACUC App. Date ________
- ☐ HUMAN SUBJECTS (GPG II.C.11) Exemption Subsection ______ or IRB App. Date ______
- ☒ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.9) DNK ENG
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
School of Marine Sciences	Darling Marine Center 193 Clark's Cove Road Walpole, ME 045733307 United States
PI/PD FAX NUMBER 207-563-3119	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Peter A Jumars	PH.D.	1974	207-563-3146	jumars@maine.edu
CO-PI/PD Lee Karp-Boss	PhD	1998	541-737-2415	lkarpboss@oce.orst.edu
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

Electronic Signature

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 02-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix A of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Appendix B of the Grant Proposal Guide.

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME James S Ward	Electronic Signature	Feb 7 2002 3:10PM

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
207-581-2200	umgrants@maine.edu	207-581-1446

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

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PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 02-2	FOR NSF USE ONLY
NSF 02-2	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) OCE - BIOLOGICAL OCEANOGRAPHY	0220284

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				042803536	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY?
916001537	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
University of Washington	University of Washington 3935 University Way NE Seattle, WA. 981056613
AWARDEE ORGANIZATION CODE (IF KNOWN): 0037986000	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply)
(See GPG II.C For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **Collaborative Research: Form and Function of Phytoplankton in Unsteady, Low Reynolds-Number Flows**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ 356,512	36 months	09/01/02	

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- ☐ HISTORIC PLACES (GPG II.C.9)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.C.11)
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- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

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CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 02-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

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Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

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Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Karl J Valentine**	**Electronic Signature**	**Feb 8 2002 3:41PM**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 02-2	FOR NSF USE ONLY
NSF 02-2	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) OCE - BIOLOGICAL OCEANOGRAPHY	**0221003**

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
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356002041	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
Purdue University	Purdue University 610 Purdue Mall West Lafayette, IN. 47907
AWARDEE ORGANIZATION CODE (IF KNOWN) 0018259000	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

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(See GPG II.C For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **Collaborative Proposal: Form and function of phytoplankton in unsteady, low Reynolds-number flows**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ 207,997	36 months	09/01/02	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

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- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
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PI/PD FAX NUMBER 765-494-0539	

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CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

Electronic Signature

CERTIFICATION PAGE

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(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Diane E Troyer**	**Electronic Signature**	**Feb 14 2002 3:43PM**

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A PROJECT SUMMARY

Small-scale flow dynamics at low Reynolds numbers (***Re***) are important to phytoplankton cells in delivery of nutrients, sensory detection by and physical encounter with herbivores, accumulation of bacterial populations in the “phycosphere” or region immediately surrounding phytoplankton cells and coagulation of cells themselves as a mechanism terminating blooms. In nature most phytoplankton experience unsteady flows, *i.e.,* velocities near the cells that vary with time due to the intermittency of turbulence and to discontinuous, spatially distributed pumping by herbivores. This unsteadiness has not previously been taken into account in models or measurements with plankton. Moreover there have been decade- and century- long lags in moving relevant models of unsteady flow effects at low ***Re*** from applied mathematics and engineering to ecological applications. The proposal shows with engineering models that unsteady effects due to the history of formation of spatially extensive flow perturbations or wakes should be important to unsteady motions of moderately small biota and addresses the apparent impedance to information transfer across disciplines as well as developing several complementary methods to investigate effects of unsteady flow on phytoplankton. Non-swimming phytoplankton, and in particular diatoms, are chosen as the simplest case where important unsteady flow behaviors should arise.

Information transfer is addressed through a multi-level educational program, aimed primarily at graduate research assistants, undergraduate research interns, undergraduate marine sciences majors and high-school teachers. Low-***Re*** behaviors afford unusual opportunities to experience how mathematics, physics and biology inseparably catalyze understanding of phenomena that run counter to intuition. Information transfer is also fostered through international collaborations with world experts on organism-flow interaction in Cambridge (T.J. Pedley) and Copenhagen (T. Kiørboe & A.W. Visser). The entire proposal aims to accelerate the flow of understanding from modelers to measurers to users of the information and back again. Educational materials that project U.S. national standards will be developed during intensive summer workshops with the high-school teachers and be made available on the web.

Unsteady flow effects on phytoplankton will be predicted with explicit models based on singularity solutions (that involve the useful simplification that force is applied to the fluid at a small number of points) and mathematical models that include both the near field at low ***Re*** and the far field over a range of ***Re***, both representative of nature. Singularity solutions allow explicit treatment of the role of complex cell shapes. Scaled-up analog models will be placed in a large Couette vessel to better visualize behaviors for both the research and teaching efforts. Natural-scale, but simplified, unsteady flows will be produced in smaller Couettes (nested, counter-rotating cylinders with seawater in the gap between the two cylinders) containing live phytoplankton and will be quantified by magnifying, particle-imaging velocimetry (PIV). Image analysis will be used to measure translation, rotation and flexural deformation of the phytoplankton.

These studies will test various hypotheses derived from the general thesis that cell shapes and mechanical properties interact with unsteady flows to produce potentially fitness-enhancing, relative motions of the cell or chain and its surrounding fluids. A basic hypothesis is that unsteady fluid motion will interact with bending of cells to produce relative motion of fluid and phytoplankter. A very exciting prospect is that periodic instabilities known to arise at low ***Re*** may allow flexible organisms to act as “self-organizing engines” — through elasticity to harness energy from decaying turbulence and thereby move relative to the fluid. It is also expected that this study of passively bending structures in unsteady flows will help to understand the use of flexible appendages in swimming. The work is likely to aid significantly in associating functions with the shapes and spines of microplankton that are used in the identification of fossil specimens. By including relevant, unsteady fluid motions at low ***Re***, the study will also provide firmer linkages between form and function in living plankton in the size range from 10 - 1000 μm that many large phytoplankton, invertebrate and fish larvae and other small zooplankton occupy.

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For font size and page formatting specifications, see GPG section II.C.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

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C PROJECT DESCRIPTION

C.1 Progress under current NSF grants

C.1.1 SUMMARY OF SCIENTIFIC RESULTS FROM PRIOR WORK

Grant Number	*OCE-9617701*	*CCR-9980058*	*CTS-9415280*
Grant Title	*Food substrates & digestive capabilities of marine deposit feeders*	*Coordinated motion of natural & man-made groups*	*Investigation of nonpremixed, reacting turbulent flows*
Tenure of Award	*01/04/97 - 09/30/02 (incl 30-mo, no-cost ext.)*	*15/09/99 - 31/08/02*	*01/01/94 - 31/10/98*
PI	*P.A. Jumars*	*A.S. Morse, D. Grünbaum et al.*	*J.J. Riley & G. Kosàly*
Total Award	*$315,761*	*$2,600,000 (est.)*	*$320,603*

Jumars' current NSF grant applies quantitative advection-reaction-diffusion approaches from chemical engineering (Jumars & Martínez del Rio 1999; Jumars 2000a,b) to the study of deposit feeding in marine invertebrates, and has a small component of unsteady-flow-related work associated with mass transport by antiperistaltic waves in guts (Rangel & Jumars, in manuscript). It funded Jumars' writing effort in a review that includes his prior NSF-funded work on benthic flow effects (Jumars *et al*. 2000). The current NSF project on deposit feeding is collaborative with UMaine (L.M. Mayer) and SUNY Stony Brook (G.R. Lopez), and has been extended by delays arising from Jumars' move to UMaine. Jumars' component supported the M.S. research of Winnie Lau (NSF Fellow; Lau *et al.,* 2002), David Rangel, and Micaela Parker (NSF Fellow; Parker & Jumars, in revision) at the University of Washington. Progress is updated in the form of summaries and preprints at <http://www.umaine.edu/~marine/jumars/paj.html> including a recent synthesis (Mayer *et al*. 2001, available in pdf format for download at that url). Jumars' most recent work on flow-organism interactions at small scales (with Karp-Boss) has been funded by the Office of Naval Research and is not summarized here but instead in the proposal and CVs.

Grünbaum's early work on the functional morphology of low Reynolds-number (***Re***) flows was funded by NSF grants to C.D. Harvell, and H. Othmer *et al*. Grünbaum (1995) used singularity methods similar to those we propose below to develop a model of cilia-induced feeding currents within bryozoan colonies, and generated explicit, quantitative predictions about how colony morphology affects feeding performance. Grünbaum (1997) experimentally supported these predictions, demonstrating a relationship between colony fitness and colony morphology mediated by hydrodynamic constraints. Grünbaum *et al*. (1998) used Immersed Boundary Method simulations to investigate pumping performance at low and intermediate ***Re*** in ciliated arrays in ascidians, bivalves, brachiopods, bryozoans, phoronids, polychaetes and larval echinoderms. They showed that the ciliated array in *Mytilus edulis* operates close to a flow-maximizing geometry. Grünbaum's recent and current NSF grants link individual-level biomechanical and sensory constraints to population-level ecological and evolutionary consequences in a variety of taxa (Grünbaum & Veit, in review; Veit & Grünbaum, in prep.). Grünbaum (2002) develops nondimensional indices quantifying the relative importance of dispersive and demographic processes and demographic processes in spatio-temporally variable plankton populations. This research builds on extensive analyses of biological random walks (Grünbaum & Okubo 1994; Grünbaum 1994, 1998a,b, 1999, 2000; Edelstein-Keshet *et al*. 1998; Flierl *et al*. 1999) and utilizes an automated tracking system that quantifies 3-D motion (Grünbaum & Parrish, in prep.) to determine behavioral parameters in schooling fish, foraging zooplankton, and other organisms.

In earlier research funded by the NSF, Riley developed the equations of motion for low-***Re*** spheres in unsteady flow (Riley 1971; Maxey & Riley 1983) and applied them to the first direct numerical simulations of low-***Re*** number particle motions in turbulent flow (Riley & Patterson 1974). Under the most recent NSF grant (table above), Riley performed direct numerical simulations of turbulent reacting flows. He developed and tested one of the first subgrid-scale models for the large-eddy simulation of nonpremixed, turbulent reacting flows. This grant resulted in 11 peer-reviewed journal articles and 2 book chapters (*e.g.,* de Bruyn Kops & Riley 1998; 2000). Data sets available from this work include homogeneous decaying turbulence, turbulent scalar mixing layers, and chemically-reacting scalar mixing layers.

C.2 Introduction

C.2.1 Fluid dynamics and phytoplankton

No biological-physical interactions have been more central to biological oceanography than effects of fluid motions on phytoplankton *(e.g.*, review by Wyatt & Jenkinson 1993). Ramón Margalef long has championed flow macro- and microhabitats as important niche dimensions among phytoplankton (*e.g.*: Massutti Oliver & Margalef 1950; Margalef 1978; Margalef 1997). Others have carried these ideas in many directions and dimensions (*e.g.*: Gili *et al*. 2001; Smayda & Reynolds 2001). Flows move cells toward or away from light and mix or advect nutrients into the euphotic zone, and the details of such advection, shear and mixing are integral to understanding of phytoplankton spatial structure (*e.g.,* Franks 1995) and growth dynamics (Mann & Lazier 1996).

Small-scale flows are no less important. Inefficiency in delivery of nutrients by molecular diffusion over all but the smallest spatial scales generated early and continuing interest in relative flow past cells (Munk & Riley 1952; Pasciak & Gavis 1974, 1975). Whereas relative flows produced at natural turbulence intensities cannot in general accelerate delivery of low molecular-weight solutes to bacteria 1 μm in diameter (Berg & Purcell 1977; Purcell 1978), flows can be important to cells that exceed a few tens of micrometers (reviewed by Karp-Boss *et al*. 1996). Limitation issues for phytoplankton include inorganic carbon (*e.g.,* Riebesell *et al*. 1993). Solute transports by advection and diffusion are also important in the other direction, as chemical cues for herbivores, as cues in chemotaxis and sources of food for heterotrophic bacteria (*e.g.*: Jackson 1989; Bowen *et al*. 1993; Blackburn & Fenchel 1999) and potentially as signal compounds to other phytoplankton in sexual reproduction (*e.g.*: Weissburg 2000; Wolfe 2000).

Small-scale flows are fundamental to interactions. They influence relative velocities between particles, and thus the likelihood that one phytoplankter will encounter another and coagulate with it or that the cell will reach a herbivore's sensory field and feeding appendages (*e.g.*: Andrews 1983; Marrasé *et al*. 1990; Osborn 1996; Lewis & Pedley 2001). Flows affect delivery of information as pressure, velocity or concenration. At high rates, shear may cause damage (*e.g.*: Schöne 1970; Thomas & Gibson 1990; Hondzo and Lyn 1999; Juhl *et al*. 2001; Moisander *et al*. 2002). Shear affects spination reversibly in dinoflagellates (Zirbel *et al*. 2000), and systems for sensing shear stress have been documented in diatoms (Falciatore *et al*. 2000).

C.2.2 The problems that we propose to address

- Natural flows at the scale of individual phytoplankters are ***unsteady***, approximately linear shear flows arising by viscous dissipation from the smallest turbulent vortices: Flow magnitudes and directions change frequently with respect to an origin through the center of mass of a cell.
- Flows at this scale have been simulated primarily as ***steady,*** one-dimensional, linear shear flows, largely in Couette tanks.
- Review of engineering models and data reveals that unsteadiness in natural flows is likely to have substantial effects on the motions of particles, even for rigid objects of simple geometries, when those particles are of order 10 - 1,000 μm in diameter and have particle densities (mass volume^{-1}) near those of plankton.
- Models of turbulence effects on phytoplankton often parameterize cells as rigid spheres or spheroids. Phytoplankton shapes and mechanical properties can vary widely and are likely to interact strongly with unsteady shear flows.
- Little is known about flows around individual phytoplankton cells — even in steady shears — and motions of the cells themselves have been modeled only for idealized cell shapes and analyzed empirically only by relatively gross parameters (*e.g.*, rotational frequency in steady shear; re-orientation in simulated intake siphons or flow cytometer intakes). Quantification of flow fields around cells is crucial to further progress.
- We will use PIV (particle-imaging velocimetry) and image analysis of the moving phytoplankter to quantify local flows and motions of real phytoplankton cells first in steady shears as a training set relevant to past studies. We will use very recent, unsteady-flow generalizations of classic singularity solutions and numerical approaches to predict behaviors of realistically shaped cells. We then will move to measure deliberately unsteady shears in Couette vessels. Observations will include cells of diverse geometries and material properties as well as model objects of known material properties in experiments with scaled-up mimics.

- We will test several hypotheses derived from the general thesis that unsteady forces are important, through interactions with cell shapes, appendages and material properties, in producing relative motion of non-swimming phytoplankton cells and chains through the water and in determining their surrounding solute, velocity and pressure fields. Among the most novel hypotheses is that flexure of cells and chains interacts with unsteady flows to amplify relative motion through the fluid. Testing these hypotheses can be expected to reveal relations between environment, form and function, thereby aiding interpretation in micropaleontology.
- The low-***Re*** world provides ideal subjects for connecting mathematics with physics, chemistry and biology in teaching materials that project the national standards. We propose an educational effort that includes participation by high school teachers in developing curricular materials.
- Why us? We have assembled a team that combines skills in visualization and measurement (Wereley), theory of unsteady, low-***Re*** flows (Daniel, Grünbaum, Pedley & Riley) and foraging theory and experimental experience with flow effects on phytoplankton (Karp-Boss & Jumars) to both pose and test cogent hypotheses. We have added collaborators (Kiørboe & Visser) with strong records of accomplishment and communication in related problems under steady flows to sharpen our experimental designs and accelerate dissemination of our results into both zooplankton research and educational media.
- Why do it now? Breakthroughs have recently been made in analytic modeling of unsteady flow effects at low ***Re*** that allow us to idealize unsteady motions analytically. Numerical approaches have matured, and measurement and visualization technologies have only now reached the resolution to deal with flows surrounding an individual phytoplankter.
- Why do it at all? Unsteady flows around phytoplankton set limits on solute fluxes to and from the cell, and thus are important to nutrient limitation, chemical detection by herbivores, leakage of photosynthates and chemotaxis by bacteria; they determine the time and space scales of the phycosphere. All particle-particle interactions, including sperm-egg and predator-prey encounters, necessarily involve unsteady terms, since approaching particles induce unsteady flows on each other (*e.g.,* Pienkowska 2001). Shapes and material properties of phytoplankton cells interact with relative flows; our results should aid in understanding fossil morphologies and evolution of plankton. Work with passively bending and moving cells and chains can help to decipher the more complicated role of combined active-passive flexure in limb motion at low ***Re.***

C.2.3 SMALL-SCALE FLOW REGIMES AROUND PARTICLES; AN INTRODUCTION AND HISTORY

Humans live in a turbulent, gaseous world that gives little intuition for viscous flows. For that reason, computations have replaced intuition into interactions occurring at low ***Re*** in steady flows, *i.e.,* sinking or swimming through stagnant water. No single, short exposition has offered a clearer window than Purcell's (1977) classic and conversational, "Life at low Reynolds number." Berg's (1983) monograph solidified the foundation of this understanding by bringing it within reach of biologists possessing moderate mathematical skills.

Many have contributed toward putting life at these small scales into the more natural marine context of a turbulent ocean, from Munk & Riley (1952) onward. Lazier & Mann (1989), among others, opened the window wider for non-specialists by highlighting the organized behavior of fluids below the Kolmogorov scale, where the steady component of motion can be approximated as a linear shear. Not only are linear shear flows tractable computationally, they also are amenable to simulation in simple flow devices, such as Couette tanks (Fig. 1).

Despite the fact that shear is important to a host of encounter processes, its effects were slow to enter the ecological literature from coagulation and sedimentation in geology. Shear brings even neutrally buoyant particles together through what has is known as shear coagulation (McCave 1986), and can terminate blooms by agglomerating phytoplankton into rapidly sinking aggregates (Jackson 1990; Hill 1992). The same shear supplies prey to the volume swept out by sensory fields of suspension feeders and predators (Rothschild & Osborn 1988; Shimeta *et al*. 1995). Likewise, the same mechanism may contribute to fertilization through enhancement of contact rates between sperm and eggs (*e.g.*: Denny & Shibata 1989; Levitan1995), although there is evidence as with suspension feeding and particle coagulation that too much turbulence can reduce *effective* encounter rate by dispersing high concentrations, disrupting sensory cues and forcefully separating the relevant particles before the specific interaction can be consummated

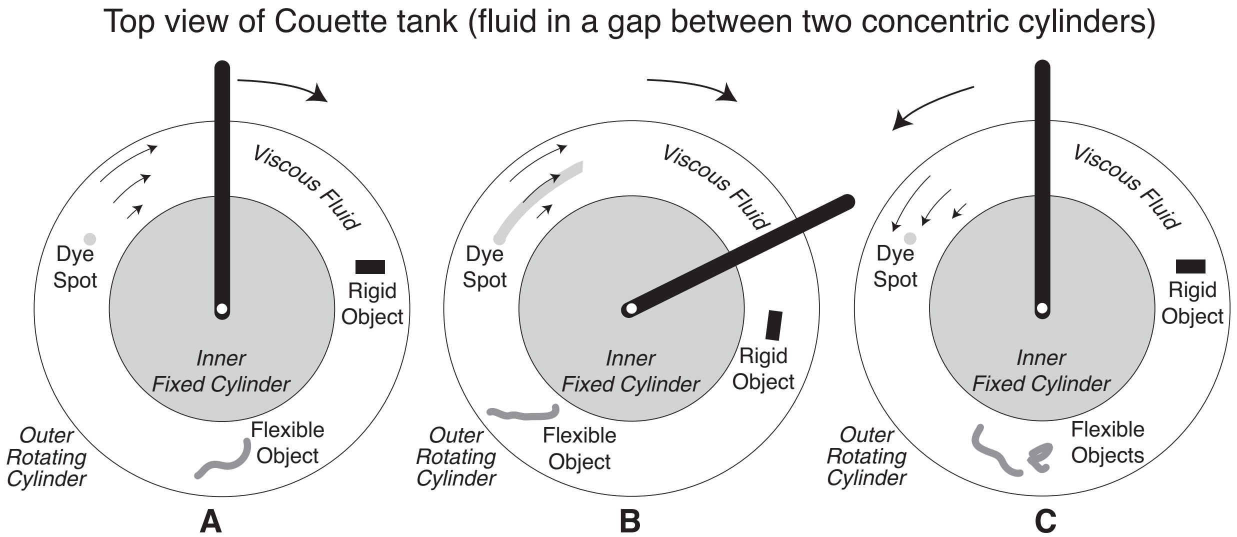

Fig. 1. Schematic top view of a Couette device with its axis vertical and its inner cylinder fixed, illustrating effects in creeping, viscous flows on water parcels (dye spot) and on both rigid and flexible objects (after Taylor 1966). (A) The outer cylinder is rotated clockwise by hand, (B) shearing the fluid and placing rotational stresses on the objects. When (C) the crank is reversed and returned to its starting position (even after several complete revolutions), the dye spot and the rigid object recover their initial positions and orientations. Flexible objects in general do not.

(Mead & Denny 1995). Steady shears also produce less appreciated behaviors of single particles. Jeffery (1922), for example, calculated that steady, one-dimensional shear causes periodic, three-dimensional rotation of spheroids, and his calculations were confirmed in engineering experiments long ago (*e.g.,* Trevelyan & Mason 1951). It has taken 75 yr, however, for his insight to enter biological oceanographic applications (*e.g.:* Pahlow *et al*. 1997; Karp-Boss & Jumars 1998).

More importantly for the present proposal, flows past most organisms or their appendages are unsteady: Time derivatives of local flow velocities about individual appendages or whole organisms are nonzero. Shears from decay of natural turbulence cannot be steady, especially at the smallest scales where vorticity is diffused most effectively away by viscosity, and where inertia passes to viscosity and dissipates as heat. One of the signature characteristics of turbulence, at last confirmed by direct observation, is its intermittency, including extreme accelerations too large to measure with most devices. Values of acceleration away from the mean are both far more extreme and far more frequent than under a normal or bell-shaped curve (La Porta *et al*. 2001). Below the Kolmogorov scale in upper mixed or bottom boundary layers, flow directions and magnitudes rarely persist more than a few tens of seconds. Even those organisms that swim steadily thus experience accelerations from shifting flow fields, but many organisms, from “tumbling-and-running” bacteria to burst-swimming copepods and larval fishes at the transition to higher ***Re*** (*e.g.:* Müller *et al*. 2000; Yen 2000; van Duren, in review) also experience unsteady flows of their own creation, even during tranquil interludes symptomatic of the local intermittency of turbulence. Undulatory motions of appendages characteristic of both fishes and crustaceans at both high and low ***Re*** are inherently unsteady, albeit periodic, as are Jeffery orbits. Flicks or sniffs of chemosensory appendages, too, are unsteady, as the terms vividly indicate, whether in water or in air, and aid in sampling new fluid parcels (Loudon and Koehl 2000; Mead and Koehl 2000; Goldman& Koehl 2001; Koehl *et al*. 2001). Steady or unsteady shear thinning of diffusional boundary layers is a clear advantage in reducing detection times (Moore *et al*. 1999). Although periodic movements of individual cilia within ciliary fields can result in more-or-less steady propulsion of a protist or steady flow through a bivalve siphon, markedly unsteady and aperiodic motions of individual cilia, apparently controlled by sensory inputs, are part of important “scan-and-trap” behaviors of suspension feeders (*e.g.,* Strathmann 1982; Nielsen & Riisgård 1998). Surely some of the controversy surrounding applicability of mechanisms of hydrosol filtration (*e.g.,* Ward *et al*. 2000) arises because the analytic framework in place is for steady motion (Rubenstein & Koehl

1977; Shimeta & Jumars 1991), whereas "scan-and-trap" motions are inherently unsteady. Moreover, protist swimming often involves angular accelerations in helical trajectories (*e.g.,* Crenshaw *et al*. 2000). Foraging and predator escape in these micro-organisms—and therefore their ecological impacts on planktonic communities—are determined largely by behavioral responses to unsteady delivery of chemical and hydrodynamic cues.

Recent consolidation of understanding for both steady- and unsteady-flow, low-***Re*** phenomena emboldens further exploration of unsteady flows. Visser (2001) systematized the differences between particles settling and organisms swimming. In swimming, fore- and aft-directed forces on the fluid (thrust and drag) must be equal in steady motion, and the consequent flow perturbations damp each other from the perspective of a distant observer. The body force (gravity) that propels settling particles, on the other hand, acts at a distance, and the fluid is involved only in drag. As a consequence, flow perturbations extend much farther in sinking than in swimming for a given organism size and speed (***Re***); settling at low ***Re*** has no local return circulation, whereas swimming does. A notable feature of Visser's consolidation is resort to computational flow idealizations called doublets and stokeslets. They are specific implementations of a class of solutions that we also propose to use, *i.e.,* singularity solutions, which idealize forces by distributing them over a finite number of points. For example, "doublets" (which juxtapose point sources and sinks of fluid at infinitesimal distances) can simulate steady flow past a sphere, an application that dates back over a century and has been used regularly by the mathematically inclined who are interested in biological fluid dynamics (*e.g*.: Blake & Chwang 1974; Lighthill 1975). Discrete or continuous distributions of these singularities can be used to represent complex and even motile objects immersed in low-***Re*** flows (so-called boundary integral or boundary element methods: Phan-Tien, 1987; Pozrikidis 1992; Ramia & Swan, 1994; Ramia *et al*. 1993). Until Visser's systemization, however, access and motivation of biological oceanographers to apply these idealizations has been very limited. In an exciting parallel derivation, Jiang *et al*. compared a singularity-based solution (2001a) with numerical simulations (2001b) in a finite-volume, grid-based system. They included modifications appropriate to specific copepod (steady) swimming modes and feeding currents. Of most direct significance to our proposed work, singularity solutions have just been extended to unsteady flows (Chan & Chwang 2000; Shu & Chwang 2001), so unsteady, analytic solutions are accessible to biological oceanographers for the first time.

Complementing these analytic idealizations that aid immensely in understanding and generalizing are numerical methods that allow detailed analysis of specific cases of interest and tests of generalizations. One of several notable examples is numerical solution for steady flows about a copepod (Jiang *et al*. 1999, 2001b). Perhaps even more notable, however, is that neither analytic nor numerical approaches to flow-organism interactions in limnology and oceanography have yet extended in any comparable detail into unsteady flows. We argue that they have not yet been made very broadly accessible, which forces us to try harder in melding teaching and research.

One gauge of accessibility is treatment in introductory texts of biological fluid dynamics, for example, Vogel's (1994, p. 363) accounting of forces (F) on an object in an unsteady ($\partial/\partial t \neq 0$) but uniform ($\nabla = 0$) flow:

$$F = \frac{1}{2}C_d \rho S U^2 + ma + C_a \rho V a \,. \tag{1}$$

The three terms on the right are, respectively, the quasi-steady drag of the fluid on the object, the force to accelerate the body itself, and the so-called "acceleration reaction" or "added-mass" term. C_d is a (dimensionless) drag coefficient, ρ is fluid density, S is the cross-sectional area of the object perpendicular to the flow, U is the velocity of the object relative to the fluid, m is the object's mass, a its acceleration, and C_a is the "added-mass" coefficient, which when multiplied by the fluid density and the volume, V, of the object will give the (added) mass of fluid that must be accelerated in order to change the object's velocity. Unsteady flow effects at high ***Re*** are pervasive in the *Wave-Swept Environment* (Denny 1988) and have received well due attention there (*e.g*.: Denny *et al*. 1998; Koehl 1999). Unsteady, low-***Re*** flows, by contrast and despite their ubiquity in nature, are much less evident in biological fluid dynamic or biological oceanographic applications.

The beginnings of an intuition for how, when and where unsteady, viscous flows are important to organisms and parts of organisms can be developed by writing the low-***Re*** analog of Eq. 1. The contrast is clearest if written for a sphere (of radius r_0) to remove the arbitrariness of the coeffi-

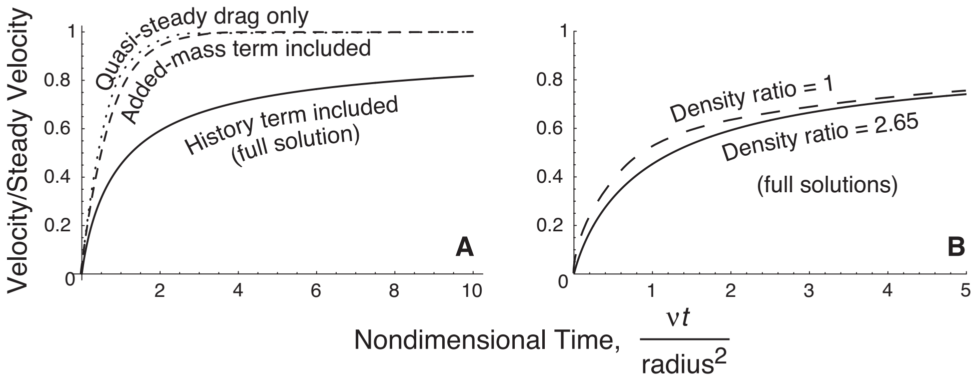

Fig. 2. Importance of the wake history term under constant acceleration force of a solid sphere from rest, following Clift *et al.* (1978); ν is the kinematic viscosity, and *t* is time in the corresponding units. **A**. Velocity versus time for a sphere whose acceleration is damped by quasi-steady drag alone, by quasi-steady drag and added mass, and by all terms, including the history term. The graphs shown are for a density ratio (solid/liquid) of 2.65. **B**. Full solutions for two different density ratios. For a density ratio of 1 (*i.e.,* neutral buoyancy) the steady acceleration that eventually would balance steady drag must be provided by a force other than gravity. With 50 μm for a dinoflagellate radius only 82% of steady velocity is achieved after 0.025 s (τ = 10). For a 0.5-mm *Noctiluca,* that time would increase to 2.5 s. For a bacterium (radius = 0.5 μm), by contrast, the time is 2.5 × 10^{-6} s, allowing the wake history term to be ignored.

cients (C) and permit direct comparison (since flow at a given ***Re*** for nonspherical objects will not be dynamically similar if either the orientation of the object or of the oncoming flow changes). Focus on a sphere (for the moment) removes these ambiguities of orientation. For simplicity and ease of direct comparison, the specific problem is the motion of a negatively buoyant particle (particle specific gravity, $\rho_s > \rho$) under the force of gravity (gravitational acceleration = g), and an upward-directed, resisting, force is taken as negative. For the sphere at *high* ***Re,*** Eq. 1 becomes

$$F = \underbrace{-\frac{0.47}{2}\rho\pi r_0^2 U^2}_{\text{quasi-steady drag}} + \underbrace{\frac{4}{3}\pi r_0^3(\rho_s - \rho)g}_{\text{body force}} - \underbrace{\frac{2}{3}\pi r_0^3 \rho a}_{\text{added mass}} . \tag{2}$$

At low ***Re,*** one can find Stokes' solution for steady drag on a sphere, $-6\pi\mu r_0 U$ in Vogel (1994, p. 341), where μ is dynamic viscosity. Added-mass terms are identical at high and low ***Re*** for the simple reason that the acceleration is instantaneous, and viscous versus turbulent behaviors of water in response have not had time to occur. But for unsteady motion, a term is still missing from Eq. 2, and we rewrite the equation explicitly for creeping flow (***Re*** → 0):

$$F = \underbrace{-6\pi\mu r_0 U}_{\text{quasi-steady drag}} + \underbrace{\frac{4}{3}\pi r_0^3(\rho_s - \rho)g}_{\text{body force}} - \underbrace{\frac{2}{3}\pi r_0^3 \rho a}_{\text{added mass}} - \underbrace{6 r_0^2 \sqrt{\pi\rho\mu}}_{\text{wake history}} \int_0^t \frac{\frac{dU}{d\tau}}{\sqrt{t-\tau}} d\tau . \tag{3}$$

The wake-history term, where τ indicates a prior time (much as in the Lotka-Volterra equation with time lags), accounts for the fact that it takes some time for near and far streamlines to adjust when an object changes speed or direction and can be interpreted as a consequence of the changing "wake" (Maxey & Riley 1983). At low body and flow ***Re,*** flow velocities propagate further from the body in nondimensional radial coordinates, making interaction with the far-ambient flow field relatively more important than at high.

History of the unsteady terms is as fascinating as the underlying science. Poisson and Stokes, still apparently motivated by "the latitude problem" (Sobel 1995), worked on periodic motions of spheroids. The practical implementation was a pendulum clock, its bob retarded by friction with air. Poisson (1831) solved correctly for the added mass on an accelerating sphere, and Stokes (1851) found the linearized, inertia-free solution for the Navier-Stokes equation. It was Boussinesq (1885a, b), not Basset (1888 a,b), however, who first derived the history term for velocities that are arbitrary functions of time. Because the history term (Eq. 3) cannot in general be calculated explicitly, it often was dropped, even from engineering applications and even when it was larger than the added-mass term (Michaelides 1997). When Daniel (1984) abstracted formulations from engineering, the history term was missing from much of the available literature, and his applications were generally for ***Re*** > 10, where a creeping-flow solution (Eq. 3) is clearly invalid. For most oceanographic and ecological applications at low ***Re***, the added-mass term has also been omitted, with the justification that it makes little difference compared with the quasi-steady term (Fig. 2). With this omission, acceleration to steady settling velocity is nearly instantaneous, leading to the conventional but flawed wisdom that acceleration times and stopping distances are very short at all low ***Re.*** We followed this erroneous path ourselves (Shimeta & Jumars 1991). The conventional wisdom *is* correct for the micrometer-sized particles that allow laser-Doppler velocimetry (LDV) and PIV (caption of Fig. 2), deflecting attention from poorer, less instantaneous tracking of flow by larger particles with larger, longer-forming wakes.

Michaelides (1997) reviewed the history term comprehensively, and in principle made understanding available to oceanographers and ecologists, but general singularity solutions for unsteady flows were not yet available (Chan & Chwang 2000; Shu & Chwang 2001). He concluded that the correct solution for a sphere in an arbitrary flow was presented by Maxey & Riley (1983), but that this solution was rarely accessed, even by engineers. Moreover, a second wake-history term should be added for non-spherical objects (Lawrence & Weinbaum 1986). History terms often are unimportant for small, dense objects in air (high excess density), but not for those same objects in water. As one might have expected, flow history rarely can be ignored in rapid oscillations of flying and swimming. We have been ambiguous intentionally with respect to how low is low ***Re,*** except to point out that the derivation of the original history term was for ***Re*** → 0. Michaelides' review includes finite ***Re*** < 1 and finite initial velocities. Even the steady drag term requires modification, as Oseen (1910) first appreciated. In truth, however, experiments have been unable to distinguish the contributions of the separate terms that act in unsteady motion; what is measured is force on the sphere or velocity of the sphere as a function of time, and a multi-term model, often with the addition of adjustable leading coefficients (particularly for non-spherical objects), is fitted. For this reason, precise curve fits for simple, rigid geometries give little or no predictive power for complex shapes (Michaelides 1997) let alone flexible, biogenic materials.

This narrative introduction gives some qualitative appreciation for the complexity of unsteady flows. *No fewer* than four dimensionless groups will characterize behavior of rigid objects in unsteady flows fully (Clift *et al*. 1978), *i.e.,* twice as many as for steady flow. But observation of real organisms (*e.g.,* Karp-Boss & Jumars 1998) or a moment's thought reveals that they are rarely rigid and spherical. Mechanical properties of organisms, in particular elasticity that removes strain in the solid after fluid stress is removed, contribute to their interactions with the flow. Such interactions of mechanical properties, in turn, have long been appreciated at high ***Re*** (*e.g.,* bending *vs*. breaking of willows *vs*. oaks). Adding solid mechanical properties and complex shapes multiplies the number of nondimensional parameters to the point that it is not feasible to distribute experiments among all combinations of nondimensional variables in only a few years.

Indeed, engineers have themselves leapfrogged the deliberate, systematic approach of dimensional analysis in simple empirical evaluations of end-member behaviors — like those that we propose. For example, engineers have placed fibers of a range of rigidities into steady shear flows and observed that a limp fiber tends to be rolled up into a ball (Arlov *et al*. 1958; Forgacs & Mason 1959). Not only does this observation make good sense, analogous with the bending of flexible algae and anemones lower into less rapidly moving bottom boundary layers during energetic events (*e.g.,* Koehl 1999), but it is immediately relevant to current topics in oceanography, *e.g.,* coagulation kinetics of flexible marine materials such as the transparent polymers that many phytoplankton produce (*e.g.,* Chin *et al*. 1998; Passow 2000). There are obvious implications for coagulation kinetics because the geometry of potentially colliding particles can be changed radically by real unsteadiness, and conversely the particle geometries produced by steady shears or stagnant water can be patently unrealistic. Quiescent periods that are part of turbulence will allow elastic materials to return toward their stress-free geometries, leading to the interesting hypothesis that coagulation under steady shear may differ radically from coagulation in unsteady flows.

The basic idea behind our approach can be traced to an educational movie narrated by G.I. Taylor (1966; Homsey 2000). The film already has inspired two manuscripts from our group (Karp-Boss & Jumars 1998; Karp-Boss *et al*. 2000). In it, G.I. Taylor demonstrates reversibility of low ***Re*** flows in a Couette (Fig. 1). A dye spot, a rigid object and a piece of yarn all are placed in it, and the outer cylinder is rotated. The dye spot "smears" to form a circle at fixed radial distance (no radial or axial spread except by molecular diffusion) and the two solid objects translate and rotate due to shear, but the bit of yarn also deforms. Upon reversal of the outer cylinder and its return to its starting position, the dye spot resumes its starting position, and the rigid object its starting position and orientation, but the bit of yarn or the analogous biogenic structure does not.

C.3 Proposed work

C.3.1 THEORY: THESIS AND HYPOTHESES

Our central thesis is that cell shapes and mechanical properties interact with unsteady flows to produce potentially fitness-enhancing, relative motions of the cell and its surrounding fluids. Our thesis obviously is so complicated that it is untestable in its entirety, so we test smaller pieces or *hypo*theses. By mapping them into our thesis, however, reviewers can determine that we are not stringing together easily testable but poorly related hypotheses (Lakatos 1970). First, however, we suggest potential linkages between unsteady flow behaviors and fitness.

Morphology is very unlikely to be dominated by a single function in an organism that requires nutrients as different as phosphate and photons, and diversity of microalgal morphologies is legendary. Nevertheless, it is possible to argue compellingly that this diversity is driven more by predation than by nutrient acquisition (Smetacek 2001). Whether defenses are resistant structures, devices designed to foil detection, or chemical repellents, however, motion relative to the water and reorientation are involved in predator-prey encounter. A phytoplankter might, for example, reduce both its areal cross section for encounter and the dimensions of its chemical trace by being limp and getting rolled up into a "ball of string" by the flow. A shortcoming of this approach, however, is reduction of the light-gathering cross section of the cell. Flexibility that relieves pressure differences across the cell or strain from shear stress also would reduce mechanical detectability of the cell (Bundy *et al*. 1998). Material properties and shape combine to make cells and chains rotate faster in steady shear than do rigid ellipsoids of comparable geometry (Karp-Boss & Jumars 1998), decreasing solute exchange by closure of streamlines (Karp-Boss *et al*. 1996) and favoring the idea of detection limitation. In addition to giving obvious mechanical defense against some kinds of predators, spines might allow local accumulation of repellent chemicals.

Spines provide protection from some predators, but unavoidably interact with the flow. For example, adding spines to an unspined cylindrical diatom may decrease sinking rates by increasing overall drag, or increase sinking rates by realigning the cell in a minimum-drag orientation. Similarly, spines may decrease transport of limiting nutrients to the cell and exudates away from the cell by reducing flow adjacent to the broader cell surface, or increase advective transport by increasing sinking velocity. "Dead space" near the cell is a safe harbor from shear for chemotactic bacteria and thus has implications for concepts of the phycosphere (Azam & Ammerman 1984). Because diffusion times scale with the square of diffusion distances, and therefore shear-thinned diffusive layers dominate fluxes, local patterns of advection relative to the geometry of the cell will be important—even if our thesis ultimately is found wanting.

Insertion of an elastic object, such as a diatom chain, into a low-***Re*** flow opens the possibility for interaction of the viscous boundary layer with elasticity of the cell or chain. At minimum, flexibility alters a diatom's hydrodynamic and chemical signature, potentially allowing it to "advertise" its presence less broadly (Yen and Strickler 1996). An intriguing possibility is that elasticity, returning the cell to its unstrained shape, would displace the cell from its chemical halo and help, analogous to squid ink, to confuse herbivores about its true spatial location. Kinetic energy of the flow is stored as potential energy, producing motion of the cell relative to the water after the movement-initiating flow has dissipated. A large class of cyclic motions relying on body elasticity should be qualitatively different from anything possible for rigid or limp objects. It will be interesting to discover whether biologically common structures have the potential to become self-organizing engines (Smith 1998, 1999) that extract useful work from shear flows, and whether organisms have evolved to exploit such possibilities. If elasticity plays a role in motion of organisms that do not swim, it also likely plays a role in organisms that do. Propulsion mechanics of appendages are likely to be tuned to useful frequencies related to their material properties. Working on non-swimming organisms affords a look at this issue in two ways. One is by comparing motion of cells of taxa that differ in rigidity. The other is by numerically modulating flexibilites and analyzing consequences for motion. Scaled up analog models multiply these capabilities.

Through this mechanism, decaying turbulence may do useful work from the standpoint of a phytoplankter. Relative motion of the cell and the fluid can thin or shed nutrient-depleted boundary layers (Karp-Boss *et al*. 1996). Conversely, it would also speed removal of wastes. A fitness-enhancing side effect with respect to herbivores might be displacement of the chemosensory cue of cell location. Relative motion of fluid and phytoplankter also complicate the issue of bacterial chemotaxis toward a diffusing source of nutrients (Luchsinger *et al*. 1999). Moreover, the rotation of even rigid cells entails velocities that are substantial with respect to bacterial swimming velocities, so both well-established rotation of cells and putative translation of flexible cells may affect stability and integrity of bacteria-phytoplankton associations. And these translations and rotations also have implications for swimming organisms (Karp-Boss *et al*. 2000) and for encounter of gametes. Indeed unsteadiness in shear already has been seen to affect fertilization success (Mead & Denny 1995), but the mechanisms of its action are as yet unclear.

We will test the general null hypothesis that adjacent flow fields, rotation and translation of diatom cells and chains are insensitive to shape and material properties. In specific experiments with cells and scaled-up models we will separate effects of shape and rigidity, and we will address all of these issues in our mathematical models. In this manner we will move from testing obvious null hypotheses toward predictive capabilities specific to shapes and mechanical properties.

C.3.2 MODELING FRAMEWORK

The modeling that we propose has two central objectives. The first is to quantify the fluid, chemical, and momentum fluxes around the complicated, highly characteristic geometries found in phytoplankton. Fluxes at these scales are impractical to measure on real organisms because sensors substantially alter the quantities being measured. A theoretical hydrodynamic model is necessary to understand the relationship between form and function. It will allow us to quantify forces on specific structural elements, distributions of hydromechanical and chemical cues of nearby predators and (or) resources, and internal forces on flexible structures. It is also easily disseminated over the internet so that other researchers and students may take early and full advantage of our efforts.

The second objective is to systematically evaluate the performance consequences of morphological variations. To understand possible selective forces on geometrical characteristics (*i.e.,* performance optima and trade-offs), we need the ability independently to manipulate positions and lengths of, *e.g.,* spines and flagella. Although we will make use of natural phenotypic and genotypic variation in our experimental observations, selective manipulations of specific morphological features are not currently possible. The model will allow us to investigate hypothetical geometries that never occurred, or that occur in the geologic record but are now extinct, shedding light on why they don't presently occur and what would be their characteristics if they did. Such explorations of conceivable morphologies are among the most informative in modern theoretical morphology (McGhee 1999). They also are a good way to improve upon our proposed choices of morphologies for detailed attention as theoretical results and laboratory observations accrue.

To achieve these objectives we must be able to model hydrodynamic processes at two different length scales simultaneously: the small-scale flows around a microplankter's often intricate geometry, and the larger-scale flows that determine the turbulent vortical motions and density and chemical variations in which the microplankter drifts or swims. A model that included both small-scale detail and large-scale environment would be prohibitively expensive to run. Therefore, our basic modeling approach is to have two interacting submodels: (1) a highly detailed, morphologically accurate simulation of unsteady, low-***Re*** flow around phytoplankton, embedded within (2) a direct numerical simulation of the larger-scale flow, including key characteristics of real fluid environments such as turbulence and stratification (*e.g.,* de Bruyn Kops & Riley 1998).

Our cellular flow submodel builds upon previous analyses of low-***Re*** flow in three key respects. First, we will dramatically increase the spatial resolution and accuracy with which we represent morphological details of real diatom cells, as opposed to idealized geometries such as spheres and cylinders. Second, we will use new hydrodynamic theory (Chan & Chwang 2000; Shu & Chwang 2001) that includes transients in Stokes flow, to remove the quasi-stationary assumption implicit in most present models. The new theory will allow us explicitly to link unsteady forces on cells from interaction with external fluid with unsteady effects due to structural flexion and flagellar propulsion. Third, we will summarize the results of the detailed models by deriving coupled systems of differential equations that concisely relate cell geometry, cell position, and fluid flow. We will use these coupled equations to embed the cellular-level flow model in realistic larger-scale flows. Such embedding has been done for idealized particles (*e.g*.: rigid spheres, Eq. 3 herein; Maxey & Riley 1983) but not for realistic cell geometries. This approach will enable us to investigate whether, when and where phytoplankton are affected by vortical structures in their turbulent environments, as predicted for point particles (Squires and Yamazaki 1995) and subsequently for both neutrally and negatively buoyant spheres (Babiano *et al*. 2000; Reigada *et al*. 2001). We are acutely aware that results can depend undesirably on starting conditions (Squires and Yamazaki 1996; Babiano *et al*. 2000).

In both modeling and measurements for the duration of this proposal, we are intentionally avoiding the many-body problem where flow fields produced by other particles in motion influence the flow fields around another (*e.g.,* Leighton & Acrivos 1987). Seawater is a dilute medium, and the problem of unsteady interaction with an isolated, flexible body is sufficiently difficult and important for our initial attention before we or others turn to particle-particle interactions.

C.3.3 Fluid mechanics background

Acceleration of seawater parcels in the vicinity of an immersed object such as a phytoplankton cell is determined by a combination of viscous forces, pressure forces, inertia, and external (body) forces such as gravity. Different types of forces have different "allometries"; viscous and pressure terms become more important relative to inertia as the characteristic length (L) and velocity (u) of the object become smaller. Mathematically, flow of a Newtonian fluid such as water is described by the Navier-Stokes equations (Batchelor 1967), which can be non-dimensionalized as

$$\nabla \cdot u = 0; \boldsymbol{Re}\left(\frac{\partial u}{\partial t} + u \cdot \nabla u\right) = -\nabla p + \nabla^2 u + f. \quad (4)$$

The first equation expresses incompressibility; the second, conservation of momentum, where pressure, p, and external force, f, are scaled by characteristic values $p_0 = (\mu u)/L$ and $f_0 = (\mu u)/(\rho L^2)$.

Ability to solve the Navier-Stokes equations is generally limited analytically by intractability of nonlinear analysis and computationally by time required. Fluid mechanicians have historically identified and analyzed situations where simplified equations for fluid motion are good approximations. When ***Re*** is very small, as it is for sinking diatoms and numerous other biological applications, fluid motion has typically been approximated by the quasi-steady Stokes equations,

$$\nabla \cdot u = 0; \nabla p = \nabla^2 u + f. \quad (5)$$

These equations are linear, making it possible to calculate flows in complicated geometries by superpositions of fundamental "point-force" solutions known as stokeslets (Chwang& Wu 1975; Pozrikidis 1992). Oseen (1910) derived a far-field correction for this flow by adding a linearized momentum transport term, for which the fundamental solution is called an "oseenlet" (Lamb 1879; Batchelor 1967). Chan & Chwang (2000) and Shu & Chwang (2001) derived analogous solutions for the unsteady Stokes and Oseen equations. They also provide general expressions for velocity and pressure distributions for the Stokes and Oseen equations in translating and rotating coordinate systems. These expressions make it relatively straightforward to calculate the transients in forces as the velocity field relaxes towards a quasi-steady state.

Related solutions were applied to flagellate swimming in seminal papers by Gray (1953) and Hancock (1953) (reviewed by Lighthill 1975 & Brennen & Winet 1977) and have been more or less continually revisited. Grünbaum (1995) modeled the propulsive effect of a ciliated tentacle with slender-body theory based on no-penetration boundary conditions, as opposed to the no-slip boundary conditions pertaining to rigid, non-moving surfaces. More recent contributions include, among many others, investigation of low-***Re*** scanning currents (Childress *et al*. 1987), ciliary propulsion (Blake & Otto 1996), propagation of hydrodynamic signals from motile plankton (Visser

2001; Chiang *et al*. 2001), and flow in capillaries (Wang & Parker 1996) as well as flagellar propulsion (Lighthill, 1996). Gueron & Levit-Gurevich (1999, 2001) investigating hydrodynamic interactions between cilia and the internal mechanisms of ciliary beating are good examples demonstrating applicability of singularity solutions to highly complex geometries.

For our application, Stokeslet solutions have three critical features: (1) Low-***Re*** flow around any immersed cell can be modeled by a distribution of point forces that matches the cell's boundary conditions (*i.e.,* no slip at a solid surface). (2) Computational grids, which are very costly for the highly convoluted geometries typical of our organisms, are not required for this solution method. (3) It is straightforward explicitly to integrate fluid forces outside an object with structural forces within the object (*e.g.,* Grünbaum 1995). Our method, by design, will be restricted to applications where ***Re*** is sufficiently small. We can confirm the applicability of our model by computing the magnitude of neglected inertial terms in the predicted flows to show that they are indeed small compared to viscous terms, and by comparing them to experimental test cases.

Modeling will begin immediately in order to provide more specific predictions, including magnitudes of the expected effects, before the empirical component begins. It will follow the same sequence from simple to complex geometries, starting, however, with spheres as a step in quality assurance. For each experimental morphology and material property combination, we will make explicit, *a priori* predictions of particle motions in steady and unsteady flows. Grünbaum will lead this effort with realistic geometries, and Riley will from the beginning assure that it is designed to allow straighforward embedding in realistic, larger-scale, turbulent flow fields (*e.g.,* de Bruyn Kops & Riley 1998). We also will add molecular diffusion equations to calculate diffusive fluxes under various morphologies and flow scenarios. We have experience in this kind of embedding (Karp-Boss *et al*. 1996; de Bruyn Kops & Riley 2000). Simulating the flow field is the hard part; it would be foolish to miss the opportunity to simulate solute fluxes at the same time. We will implement a range of boundary conditions. Two are standard, *i.e*., constant concentration (at the external cell surface) and constant flux (across the cell surface). Although both give the same answer for simple geometries in stagnant water, they will not for more complex geometries in unsteady flow. We will also examine a variety of uptake kinetics based on active and passive molecular uptake, including facilitated diffusion. We will try them with uniform distributions of absorbers on the cell surface and then ask how absorbers should be repositioned to maximize uptake rate (*cf*. Jumars 2000b). The purpose of this modeling is to bound the effects of unsteady flow on nutrient uptake and to generate hypotheses that can be tested with molecular methods in the future (by us or others) regarding positioning of absorptive sites on cells of complex shapes.

In year 3, modeling will move past the experimental focus on flexibility, rotation and translation of cells to predict environmental implications of phenomena that are within modeling reach but beyond the scope of the experiments proposed. Following Squires & Yamazaki (1995), but adding realistic near-field flow about phytoplankton cells of finite size, we will predict effects of larger-scale turbulence on temporal and spatial (re)distribution of cells. We will do so for both nonmotile cells and swimming dinoflagellates and attempt to see whether we can also better explain observations already made on dinoflagellates in steady shear (*e.g.,* Karp-Boss *et al*. 2000)

C.3.4 Experimental design for analysis of unsteady phytoplankton motion

The workhorses of our experimental method will be duplicate Couette tanks with counter-rotating cylinders powered by computer-programmed stepper motors (Karp-Boss & Jumars 1998). They will be modified along the design of Wereley & Lueptow (1999a,b) to allow viewing from both top and sides. In principle, resolution is thus available in 3D, but we will work primarily in 2D to take advantage of the simplified spatial structure of non-turbulent Couette flow. Most of the work will be done in a plane perpendicular to the rotation axis (Karp-Boss & Jumars 1998), with checks on ambiguities and confirmation of Couette flow-field structures in an axis-parallel plane. Wereley's design allows this viewing by creating a square outer container, with a refractive-index-matched fluid between the outer circular cylinder and the squared one in which it is inserted.

Flow quantification will be by PIV (Meinhart *et al*. 2000a,b). We will use particles of order 1 μm or smaller for this imaging in order to avoid large history effects. Both PIV and LDV rely on faithful tracking of the flow by sub-micrometer particles, and this assumption of instantaneous acceleration is well substantiated by both calculations (caption to Fig. 2) and observations. PIV does not require resolution of tracer particle outlines because it uses scattering and (or) fluorescence to detect and follow bright pixels. Subresolution-scale optical detection has a long history of successful application, from determination of Avogadro's number (Perrin 1909) to wide-field tracking of bacteria with video.(Blackburn *et al*. 1998). We will, however, be sensitive to precision limits set by Brownian motion (Santiago *et al*. 1998) in testing fit to our model predictions.

The PIV and Couettes will be housed at the Darling Marine Center (DMC). Although we anticipate using them nearly full time during the three years covered in this proposal, we choose the DMC location in order to make them accessible to other investigators, as we have done in the past with our (Jumars & Nowell's) large flumes and LDV at Friday Harbor Laboratories.

Our general approach to analysis matches our and others' theoretical approaches for finite but low ***Re*** ($0 < Re < 1$) and is to divide flow about the object into two regions, a near field where Stokes flow applies, and a far field where the inertial components of the Navier-Stokes equation must also be included. We use our resolution of the velocity field to refine the boundary between the two. It is not at fixed distance, but rather varies with ***Re***. Our analysis is a three-way comparison of PIV measurement of external flow, object position and orientation (including flexion) and PIV measurement of near-field flow. Comparisons, then, will be made with the model both at the external flow-object position level and at the object-position, near-field flow level.

The general design is to create a plane of little net translation between counter-rotating cylinders (Karp-Boss & Jumars 1998). First, we locate a phytoplankton cell or chain in the field of view and determine from the CCD image its position and orientation within that field. Then the cylinders are accelerated to a relative velocity that produces realistic shear, decelerated to a stop and accelerated to the same relative velocities but opposite the initial direction) before being decelerated to a stop. If the body is rigid and we stay at low ***Re****,* this procedure should return the cell to the field of view and its initial orientation. We will test the system for return to the same position with neutrally buoyant, plastic spheres, although orientation will not be possible to determine. Then we will move to the triangular form of *Cylindrotheca*. Spin-up and spin-down (unsteady motions) are problematic complications in simulation of steady shears (Jackson 1994), but they are central to our effort, will be calculated in both senses, and will be quantified by PIV. It is clear from Jackson's (1994) arguments that without the quantification provided by PIV, spin-up and spin-down would be too complicated to use effectively for our purposes. A second hypothesis, if elastic rebound is important, is that return to the original position and orientation will depend on the period of the reversal as well as on the shear attained. We will stay within the bounds expected for Kolomogorov-scale vortices of upper mixed layers (Karp-Boss *et al*. 1996).

Our first year will focus toward getting data for only a few phytoplankton taxa. The second year will be a survey year in which we run many different taxa. Toward the goal of encompassing diversity, we will initially run single cultures of each taxon and acquire data on 25 individuals per taxon from a single batch of cells in the Couette. The number analyzed will depend on the variability observed in the first 10 (a pretest), but 25 is a reasonable estimate based on our collective experiences. We realize that the 25 acquired cells may not behave independently, as cell properties are known to vary with culture conditions and contaminants. We specifically seek to identify the combinations of shape and elasticity that will cause the cell to move farthest from its initial starting position and orientation. Two sets of measurements are of particular interest: (1) net displacement of the diatom away from its initial position, together with any change in orientation and (2) relative motion of fluid in the close vicinity of the cell from the standpoint of potential to move nutrients, chemical cues and bacteria. When we find an effect of interest, we will back up and do genuine replicates, *i.e.,* more than one culture of a given taxon to allow us to resolve between-batch from between-taxon differences with confidence. This contingency approach to generating true replicates saves substantial expense in the form of fluorescent tracer beads. The internal control is a rigid object of simple geometry to determine whether the Couette is behaving and to confirm unsteady adjustment of the fluid to the rotation.

Although this unsteady Couette does not mimic natural turbulence, and other tank designs have some advantages (*e.g.,* Sanford 1997), we are limited to designs that allow us literally to focus on single phytoplankters during their responses to the flow and to tanks of reasonable volume (order 1 liter to use tracer particles for PIV). We are also aware that phytoplankton can change their buoyancy (*e.g*.: Waite *et al*. 1997; Villareal *et al*. 1999), which technically is a cause of unsteady motion but occurs on a generally longer time scale than unsteadiness due to the turbulence cascade. We also will be sensitive to the likelihood that exopolymer filaments are important components of morphology in unsteady behavior (as are tails on kites). If mucus threads are important, we will further visualize them (Alldredge *et al*. 1993) and spend effort on modeling their dynamical role. Lastly, we will also be sensitive to the possibility that elastic polymers can induce turbulence at low ***Re***, even at very low concentration (Groisman & Steinberg 2000, 2001). Such induction of mixing might be a great adaptive advantage of exopolymer secretion. Karp-Boss has post-doctoral experience with diatom exopolymers in Pedro Verdugo's laboratory (Karp-Boss *et al*., in preparation), and we have followed such leads before (*e.g*., Dade *et al*. 1996)

In the third year, we will follow up interesting results, and in particular the taxa that show the greatest translation from their starting positions, with genuine replication, *i.e.,* multiple runs from separate batches of cultured cells. We will use ANOVA to allocate variation among individuals within tank runs, culture batches of the same taxon and taxa. Although it falls outside our taxonomic area of major focus, we also plan to try spined and unspined forms of *Scenedesmus* whose morphological changes have been induced chemically (*e.g*., Lurling & Van Donk 1997). We will use the kinematics and dynamics of the motion from our numerical modeling and PIV observations as well as direct measurement to ascertain mechanical properties (*e.g*., rigidity) of the cells. Tom Daniel (UW, letter appended) has invited us to use his single-muscle-cell devices to measure mechanical properties of phytoplankton cells, and we can use deflection of calibrated, drawn-out glass-fiber cantilevers to impart point stresses on cells and chains immersed in seawater and laid between microscopic "saw horses."

Another vehicle to understand the behavior of elastic objects in low-***Re*** flows will be scaled-up, geometrically simplified, flexible models in a large Couette with viscous liquids (specifically corn syrup, glycerin and various mixtures of water and methyl cellulose). An advantage of using models is that they can be constructed with known mechanical properties (including shapes unknown in life; McGhee 1999), whereas the real phytoplankton are complex, anisotropic composites. Moreover the large Couette is a superb learning and teaching tool, as the film that inspired us attests.

In years 2 & 3 we will also observe elastic and spined morphologies in siphon flow (Visser & Jonsson 2000). This flow is steady in the reference frame of a distant human observer, but unsteady in the reference frame of the entrained phytoplankter (Andrews 1983). Visser & Jonsson (2000) document its relevance to issues of suspension feeding. The added null hypotheses that we will test is insensitivity of results to variations in elasticity. The observations are also highly relevant in evaluating performance of instruments that draw in streams of particle-laden water, such as flow cytometers (*e.g*., Kachel *et al*. 1990) or imaging devices (*e.g*., Sieracki *et al*. 1998). Decaying turbulence and suspension-feeder intake currents are likely to be the two unsteady flows of greatest relevance in determining phytoplankton form and function.

C.3.5 CHOICE OF PHYTOPLANKTON TAXA

We focus on diatoms because of their extreme taxonomic and geometric diversity, their range of sizes that include where our calculations (Fig. 2) suggest that unsteady flow effects are most important and moreover because of the possibility of using information that we learn about function of frustule structures for paleointerpretation. We should point out that thin silicate structures are not rigid to deformation in shear or bending, and that they can be terminated or connected by chitin threads having even less flexural stiffness per unit of cross section. Still less rigid extensions of exopolymer may also influence motion. Under elasticity we (following Alexander 1968 and modern solid mechanics *cf*. Ugural & Fenster1995) include both rubbery, entropy-derived elasticity characteristic of cross-linked polymers and elasticity due to internal energy, as that of a clock spring. The deformations that we have observed in diatoms (Karp-Boss & Jumars 1998) arise from shear and bending moments, not from purely tensile stresses, and by "elastic" we mean behavior that returns the chain, spine, thread or polymer filament to its stable shape in still water.

We will start with individual, large cells rather than chains or colonies. The triangulate form of *Phaeodactylum* is a logical target for a rigid cell whose orientation can be determined easily and whose shape is likely to yield to simple singularity solutions. *Cylindrotheca* likewise possesses a relatively simple shape, but its long terminal spines have some flexibility, making it a target for inclusion in the first year's work. Depending on difficulty of experimental protocols and modeling, we will either progress next to very long, terminally spined cells of *Rhizosolenia* or regress to barrel-shaped cells of *Odontella* or *Biddulphia*.

In the second year, we will progress to chains. *Leptocylindrus* is the first target because of its linear array of simple, cylindrical cells and lack of large spines. *Chaetoceros* presents a number of interesting geometries, the most interesting perhaps being a helical coil, present in several strains. A possibility suggested by this shape and G.I. Taylor's film is that in unsteady motion, the chain can "corkscrew" into new water. *Chaetoceros* species also present a range of interesting rigidities because the connecting spines are variably interdigitating and fused. *Thalassiosira* presents an interesting comparison because cells are connected by thin organic strands, making the chains much more flexible than most others.

A complication with *Thalassiosira,* and likely with other chain formers, is that chain formation and geometry is affected by flow (R. Andersen, Bigelow Labs, unpublished; Karp-Boss, unpublished). This feature argues for the importance of flow effects. We have three Couettes operated by turntables salvaged from record players (Shimeta *et al*. 1995). Although they are incapable of counter rotation or programmed changes in rotation speed, they make excellent culture vessels with reproducible flow conditions. Chain cultures will be grown, at least in their final batches, in these Couettes.

Jan Rines (URI) <http://thalassa.gso.uri.edu/> displays many phytoplankton morphologies, including the spirals that we note <http://thalassa.gso.uri.edu/ESphyto/list/taxa/chdebil/chdebil.htm>, and by linking her Nomarski image <http://thalassa.gso.uri.edu/ESphyto/list/taxa/ditbright/ditbright.htm> to Isao Inouye's SEM <http://www.biol.tsukuba.ac.jp/~inouye/ino/st/baci/Ditylum.GIF> also shows the increased resolution that scanning electron microscopy provides for geometric modeling.

Cells chosen for the Couette experiments will be imaged by scanning electron microscopy (SEM) to determine morphology precisely for modeling purposes and to look for evidence of bacterial attachment to the cell itself. Although attachment might at first appear irrelevant to our flow analysis, bacterial attachment is rarely random, and can be enhanced in local regions of greater solute flux (*e.g.,* de Beer & Kühl 2001).

C.4 Broader impacts of the research activity

C.4.1 Education

A strong undercurrent of this proposal is that access of relevant small-scale flow information to biologists has been limited. Details of the laminar world have in principle been accessible since the classic derivations upon which almost all low-***Re*** work is based (Lamb 1979; Batchelor 1967), but limited accessibility to biologists is illustrated by the long times for steady shears and Jeffery orbits to enter the biological literature. The field of biomechanics within biology — and particularly within ecology — has blossomed in large measure due to the exposure of large numbers of students to a broad base of knowledge (Vogel 1981; Wainwright *et al*. 1976; Denny 1988, 1993). A growing number of current practitioners, many of them students of the foundation builders, have built elegantly upon it. We suggest that the base of common biological knowledge of unsteady, low-***Re*** phenomena is unconsolidated and therefore less accessible and less suitable to build upon. We propose a consolidation built on high-school through graduate exposure. This exposure serves two purposes. It assists in understanding of these important biological phenomena by setting additional and better prepared minds upon them. Second, it provides an ideal set of case studies where physics, mathematics, chemistry and biology travel together to solve real-world problems in biomechanics and solute transfer.

We propose a continuum of educational experiences. One graduate student will be resident at Purdue and one at the University of Washington. They will be trained in these new, quantitative approaches — and we anticipate will carry them to new heights. We propose to continue providing research experiences for undergraduates. For example, the Darling Marine Center has an active REU and other undergraduate programs, and one Bryn Mawr REU student (Rachel Schwartz) from Jumars' lab presented her results at the ASLO meeting in Albuquerque in 2001.

The centerpiece of our educational effort in this proposal, however, is a focus on high-school teachers. We can think of no better vehicle to communicate the integration of math, physics and biology than the low-***Re*** world, and such integrated exposure is rare at this or any other educational level. In the second summer, we propose to choose one high-school teacher from Maine and one from Washington and send them to the Darling Marine Center for a month. Jumars has developed a course, relying on Vogel's (1994) text, but giving greater emphasis to low ***Re*** and to mass and information transfer, for junior-senior level undergraduates in marine sciences and has taught it each fall since 2000. Students in this class each year have demonstrated understanding of each term in Eq. 3. It is a hands-on, flow-tank-centered course, including simple beaker-level demonstrations of low ***Re*** behaviors — some of which have now stood the test of middle-school presentations. We propose to select material from this course and our ongoing research here to fold into an effort, concentrated among Jumars and the two high school teachers, to develop curricular materials about organism-flow interactions that integrate math, physics and biology while teaching to the national standards. This material for potential high-school use will be mainly concerned with simpler, steady-flow phenomena, but will include visualizations in the large Couette. The undergraduates in Jumars' course have diverse backgrounds, and an approach that has proved useful is parallel development of the material in mathematical, pictorial (including animations), graphical, written and historical (who did what when) form. In addition to this parallel treatment, students also get a more typical integration as found in textbooks. The added value of the separate, parallel treatments is that students find their most comfortable access and use it as a stepping stone into skills with which they have less comfort, toward fuller integration. To allow all the senior and junior investigators to participate, we will make all these materials available on the web in both html and pdf formats. They will include sample questions (with answers) and descriptions of sample laboratory exercises so essential for inquiry.

In the third summer, these same two high-school teachers will be workshop leaders of groups of six additional high school teachers who will come to the Darling Marine Center (Maine teachers) or the Friday Harbor Laboratories (Washington teachers) to work with the materials abstracted the previous summer and perfect them further. These experiences will be intensive, ten-day affairs. The two graduate RAs will be assistants in both summers' exercises.

The key is to select participants well. In Maine, we have enlisted the aid of Maine's Math and Science Teaching Excellence Collaborative (see letter appended), a five-year, NSF-funded collaboratory to promote excellence in math and science teaching in K-12. In Washington, Grünbaum is networking with specific high school teachers at both public and private schools and has enlisted the aid of Trish Morse of the Zoology Department, who has extensive experience with educational standards (*e.g.,* Morse *et al.* 2001). She has expressed interest in being a science partner for the teachers during their Friday Harbor stays (e-mail appended).

C.4.2 Global perspective

We have enlisted Tim Pedley (Cambridge) to assist us in adapting general singularity solutions to complex geometries and in coupling organism mechanics with flow mechanics. We are also fortunate to have enlisted the collaboration of Thomas Kiørboe & Andy Visser of the Danish Institute for Fisheries Research (letter appended). They have been leaders in simplified yet very general quantification of flow interactions in the plankton (Kiørboe & Visser 1999; Visser 2001). This direction of unsteady-flow effects is a logical next step for them as well as for us. We will certainly use their past results extensively in developing the curricular materials, and we plan to share laboratory and measurement facilities for advanced research efforts. Notably, their laboratories contain various pieces of equipment for production of simplified flow components (Kiørboe *et al.* 1999), and we will be acquiring not only a PIV but very sophisticated Couette devices. We expect to exchange designs, PIs, graduate students and undergraduates for research of mutual interest. Although our results will be limited to phytoplankton, unsteady-flow effects are at least as interesting for heterotrophic protists and animal plankton. Both the Darling Marine Center, where the PIV and Couette devices will be based, and the Danish Institute for Fisheries Research are ideally set up for visiting investigators — as a successful track record in each place documents. We believe that we have set up an effective network to speed biological oceanographic application of useful engineering approaches that will illuminate classic problems of form and function in a new light.

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BIOGRAPHICAL SKETCH

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A. PROFESSIONAL PREPARATION

B.A.: 1969, University of Delaware, Newark, Delaware (Biological Sciences)
Ph.D.: 1974, Scripps Institution of Oceanography
University of California, San Diego, California (in Oceanography) with R.R. Hessler
Dissertation: "Dispersion patterns and species diversity of macrobenthos in two bathyal communities"
Postdoctoral work: 1974-1975, USC, with Kristian Fauchald in polychaete systematics

B. APPOINTMENTS

1999 - present	Professor of Oceanography and Marine Sciences, Darling Marine Center, University of Maine
1999 - 2001	Affiliate Professor, University of Washington, Seattle, WA
1983 - 1999	Professor, School of Oceanography, University of Washington
1992 - 1993	Acting Director, University Research Initiative in Marine Bioremediation
1986 - 1992	Editor, Limnology and Oceanography
1979 - 1983	Associate Professor, Department or School of Oceanography, University of Washington
1980 - 1982 (on leave)	Oceanic Biology Program (Code 422CB) and Sediment Dynamics Program (Code 425GG), Office of Naval Research, Arlington, Virginia
1975 - 1979	Assistant Professor, Department of Oceanography, University of Washington
1974 - 1975	Postdoctoral Research Associate, Allan Hancock Foundation, University of Southern California, Los Angeles, California
1971 - 1974	Research Assistant, Scripps Institution of Oceanography, La Jolla, University of California, San Diego, California
1964 - 1969	Research Assistant, Department of Entomology and Applied Ecology, University of Delaware, Newark, Delaware

C. PUBLICATIONS

(FIVE MOST RELEVANT THAT PRECEDE PRESENT NSF FUNDING)

1. Shimeta, J., P.A. Jumars and E.J. Lessard. 1995. Influences of turbulence on suspension feeding by planktonic protozoa; experiments in labmiar shear fields. *Limnol. Oceanogr.* **40:** 845-859.
2. Jumars, P.A., J.W. Deming, P.S. Hill, L. Karp-Boss, P.L. Yager and W.B. Dade. 1993. Physical constraints on marine osmotrophy in an optimal foraging context. *Mar. Microbial Food Webs* **7:** 121-159.
3. Karp-Boss, L., E. Boss and P.A. Jumars. 1996. Nutrient fluxes to planktonic osmotrophs in the presence of fluid motion. *Oceanogr. Mar. Biol., Ann. Rev.* **34:** 71-107.
4. Karp-Boss, L., and P.A. Jumars.1998. Motion of diatom chains in steady shear. *Limnol. Oceanogr.* **43:** 1767-1773.
5. Karp-Boss, L., E. Boss and P.A. Jumars. 2000. Effects of shear on swimming by dinoflagellate individuals and chains. *Limnol. Oceanogr.* **45:** 1594-1602.

(FIVE ADDITIONAL)

6. Jumars, P.A. and A.R.M. Nowell . 1984. Fluid and sediment dynamic effects on benthic community structure. *Am. Zool.* **24:** 45-55.
7. Nowell, A.R.M. and P.A. Jumars. 1984. Fluid environments of aquatic benthos. *Ann Rev. Ecol. Syst.* **15:** 303-328.
8. Shimeta, J.S.and P.A. Jumars. 1991. Mechanisms of particle encounter by suspension feeders. *Oceanogr. Mar. Biol. Ann. Rev.* **29:** 191-257.
9. Jumars, P.A., J.E. Eckman and E. Koch. 2001. Animals and plants in benthic flows. pp. 320-347 *in* B. Boudreau and B.B. Jørgensen, Eds. *The Benthic Boundary Layer: Transport Processes and Biogeochemistry.* Oxford Univ. Press, NY.
10. Schmidt, J.L. and P. A. Jumars. 2002. Clonal fitness of bacteria predicted by analog modeling. *BioScience,* in press.

D. SYNERGISTIC ACTIVITIES (FIVE OF MANY; SELECTED FOR DIVERSITY)

Cross-trained many non-biological oceanographers in the basic concepts of biological oceanography through an interdisciplinary course at the graduate level and a text tailored to it (1983-1998)

Edited *Limnology and Oceanography for six years* (1986-1992; as sole editor for the first four years); now President Elect of American Society of Limnology and Oceanography

Maintain a web site on how science is done — that is widely used by secondary teachers

Co-chaired (with Mark Hay) review and prognosis of biological oceanography for the National Science Foundation (OEUVRE — Ocean Ecology: Understanding and Vision for REsearch)

Participated in the just-completed synthesis effort (aka Decadal Planning, leading to the report, *Ocean Sciences at the New Millenium*) to combine and update the results of the disciplinary reports in biological, chemical, geological and physical oceanography

E. COLLABORATORS & OTHER AFFILIATIONS

COLLABORATORS
Mimi A.R. Koehl, UC Berkeley (co-author on manuscript in preparation, 2002)
Glenn Lopez, SUNY Stony Brook
Faculty of the School of Oceanography, University of Washington (conflicted through my continuing affiliate status there and abundant collaborations)

GRADUATE AND POSTDOCTORAL ADVISORS
Robert R. Hessler, Scripps Institution of Oceanography
Kristian Fauchald, U.S. National Museum of Natural HIstory, Smithsonian Institution

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Robert J. Feller , U. South Carolina)
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Craig R. Smith, U. Hawaii

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James E. Eckman, Office of Naval Research
Eugene D. Gallagher, U. Mass. Boston
Brian T. Hentschel, San Diego State U.
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Lee Karp-Boss, Oregon State University
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Jeff Shimeta, Franklin and Marshall College
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Robert A. Wheatcroft (co-adviser with A.R.M. Nowell), Oregon State University

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A. Professional Preparation

B.Sc.: 1989, Hebrew University, Jerusalem, Israel (Biology)
M. Sc.: 1991, Hebrew University, Jerusalem, Israel (Ecology & Oceanography)
Ph. D. 1998, Unversity of Washington (Oceanography, with P.A. Jumars)
Title: "Phytoplankton-flow interactions in relation to cell size and morphology"
Postdoctoral work: 1999-2000 with Pedro Verdugo, UW, in biopolymers
Postdoctora work:2000-2002 with Patricia Wheeler, OSU, in phytoplankton ecology

B. Appointments

2002 -	Assitant Research Professor, School of Marine Sciences University of Maine, Orono, ME
2001 - 2002	Postdoctoral Research Associate, College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR
1998 - 1999	Postdoctoral Research Associate, Department of Bioengineering, School of Medicine, University of Washington, Seattle, WA
1992 - 1998	Research Assistant, School of Oceanography University of Washington, Seattle, WA

C. Publications

(five most relevant to the proposed study)

1. L. Karp-Boss, E. Boss and P. A. Jumars. 2000. Motion of dinoflagellates in a simple shear flow. *Limnology and Oceanography,* **45:** 1594-1602.
2. Karp-Boss L. and P.A. Jumars, 1998. Motion of diatom chains in a steady shear flow. *Limnology and Oceanography* **43:** 1767-1773.
3. Karp-Boss L., E. Boss and P.A. Jumars, 1996. Nutrient fluxes to planktonic osmotrophs in the presence of fluid motion. *Oceanography and Marine Biology, an Annual Review* **34:** 71-107.
4. P.A. Jumars, J. W. Deming, P.H. Hill, L. Karp-Boss, P. L. Yager and W. B. Dade, 1993. Physical constraints on marine osmotrophy in an optimal foraging context. *Marine Microbial Food Webs* **7:** 121-159.
5. Genin, L. Karp and A. Miroz, 1994. Effects of flow on competitive superiority in Scleractenian corals. *Limnology and Oceanography* **39:** 913-924.

(additional)

6. Sagi A., L. Karp, Y. Milner, D. Cohen. A. M. Kuris and E. S. Chang, 1991. Testicular thymidine incorporation in the prawn *Macrobracium rosenbergii:* molt cycle variation and ecdysteroid effects *in vitro. Journal of Experimental Zoology* **259:** 229- 237.

D. Synergistic Activities

1996 - present — invited and contributing participant in a number of ASLO sessions on organism-flow interactions

E. Collaborators & Other Affiliations

Collaborators
Boss, Emmanuel, Oregon State University
Boyed, Tim, Oregon State University
Jumars, Peter, University of Maine
Pegau, Scott, Oregon State University
Wheeler, A. Patritia, Oregon State University

Graduate and Postdoctoral Advisors
Amatzia Genin (M. Sc. Advisor), Hebrew University, Israel
Peter A. Jumars (Ph. D. advisor), University of Maine
Pedro Verdugo (Posdoctoral advisor) University of Washington
Patricia A. Wheeler (Postdoctoral advisor), Oregon State University

Biographical Sketch

Kevin J. Eckelbarger
School of Marine Sciences
University of Maine
Darling Marine Center
Walpole, Maine 04573
(207) 563-3146 ext. 203: Fax (207) 563-3119
Email: KevinE@Maine.Edu

a. Professional Preparation

B.S. Marine Science, California State University, Long Beach
M.S. Marine Science, California State University, Long Beach
Ph.D. 1974, Marine Zoology, Northeastern University

b. Appointments

Director, Darling Marine Center, University of Maine, 1991-
Prof. of Marine Sciences, School of Marine Sciences, Univ. of Maine, Orono 1991-present
Director, Division of Marine Sciences, Harbor Branch Oceanographic Inst., Ft Pierce, FL 1990-91; Acting Director, 1985-87
Senior Scientist (1981-1991), Associate Scientist (1979-81), Assistant Scientist (1973-79), Harbor Branch Oceanographic Inst.
Director, Postdoctoral fellowship Program, Harbor Branch Oceanographic Inst., 1982-89
Editorial Board, Invertebrate Biology, 1994-present
Editorial Board, J. Experimental Marine Biology & Ecology, 1992-present
Associate Editor, Transactions of the American Microscopical Society, 1989-92

c. Publications. Eckelbarger has co-edited a volume on deep sea reproductive biology and has published over 80 papers on the marine biology of invertebrates including:

Five Publications most closely related to the proposed project:

Eckelbarger, KJ, CM Young, E. Ramirez Llodra, S Brooke & PA Tyler. 2001. Gametogenesis, spawning behavior, and early development in the "iceworm" *Hesiocaeca methanicola* (Polychaeta: Hesionidae) from methane hydrates in the Gulf of Mexico. *Marine Biology* **138:** 761-775

Eckelbarger, KJ and CM Young. 1999. Ultrastructure of gametogenesis in a chemosynthetic mytilid bivalve (*Bathymodiolus childressi*) from a bathyal, methane seep environment (northern Gulf of mexico). *Marine Biology* **135:** 636-646.

Eckelbarger, KJ, PA Tyler, and RW Langton. 1998. Gonadal morphology and gametogenesis in the sea pen *Pennatula aculeata* (Anthozoa: Pennatulacea) from the Gulf of Maine. *Marine Biology* **132:** 677-690.

Eckelbarger, KJ and CM Young. 1997. Ultrastructure of the ovary and oogenesis in the methane seep mollusk *Bathynerita naticoidea* (Gastropoda: Neritidae) from the Louisiana slope. *Invertebrate Biology* **116:** 299-312.

Hodgson, AN and KJ Eckelbarger. 2000. Ultrastructure of the ovary and oogenesis in six species of patellid limpets (Gastropoda: Patellogastrolpoda) from South Africa. *Invertebrate Biology* **119:** 265-277.

Five Other Significant Publications:

Eckelbarger, KJ and CV Davis. 1996. Ultrastructure of the gonad and gametogenesis in the American oyster, *Crassostrea virginica*. I. The ovary and oogenesis. *Marine Biology* **127:** 79-87.

Eckelbarger, KJ and CV Davis. 1996. Ultrastructure of the gonad and gametogenesis in the American oyster, *Crassostrea virginica*. II. The testis and spermatogenesis. *Marine Biology* **127:** 89-96.

Eckelbarger, KJ. And L. Watling 1995. Role of phylogenetic constraints in determining reproductive patterns in deep-sea invertebrates. *Invertebrate Biology* **114:** 256-269.

Eckelbarger, KJ. 1994. Diversity of metazoan ovaries and vitellogenesis mechanisms: implications for life history theory. *Proc. Biological Society of Washington* **107:** 193-218.

Young, CM and KJ Eckelbarger (eds.). 1994. *Reproduction, Larval Biology & Recruitment of the Deep-Sea Benthos*. Columbia Univ. Press, 427 pp.

d. Synergistic Activities

- Served as Associate Editor, Transactions of the American Microscopical Society for 4 yr
- Serving as consultant to Northeastern University (Boston) & Florida State University to review their marine programs and infrastructure planning for their respective marine laboratories.
-Serving as consultant to nation of Trinidad as they plan a new marine laboratory and ecosystems center on the island of Tobago.
- Member of design committee for Gulf of Maine Aquarium and Research Center, Portland, Maine?
- Member of planning committee to create K-12 marine education programs in local (midcoast Maine) school district (SAD 40).

Collaborators:

Craig Young, Harbor Branch Oceanographic Inst.
Paul Tyler, Southampton Univ., Britain
Alan Hodgson, Rhodes Univ., South Africa
Sandra Brooke, Southampton Univ., Britain
Elsa Ramirez Llodra, Southampton Univ., Britain

Graduate/Postgraduate Advisors:

Donald J. Reish, California State Univ., Long Beach (MS)
Nathan W. Riser, Northeastern Univ. (Ph.D)
Mary E. Rice, Smithsonian Inst. (postdoctoral)

Thesis Advisor:

Graduate Students: Michael Devin (Ph.D)
Postdoctoral: William Jaeckle (others > 5 yr previously)

CURRICULUM VITAE FOR THOMAS KIØRBOE

Adress: *Work*: Danish Institute for Fisheries Research, Charlottenlund Castle, DK-2920 Charlottenlund, Denmark. Tel: +45 33963401; FAX: +45 33963434; email: tk@dfu.min.dk.

Education:

- M.Sc. (Biology), University of Copenhagen, 1977
- Ph.D., University of Copenhagen, 1982
- Dr. Scient, University of Copenhagen, 1988

Employments:

- 1994-present: Professor at Danish Instituite for Fisheries Research
- 1983-1994: Research Scientist and from 1992 Senior Research scientist at Danish Institute for Fisheries Research
- 1990-1991: DANIDA advisor at Phuket Marine Biology Center, Thailand
- 1982-1983: Associate Professor, Institute of Life Science and Chemistry, Roskilde University Center
- 1979-1982: Research Scientist, Marine Biological Laboratory, University of Copenhagen
- 1979-1982: Teaching assistant, Institute of Life Science and Chemistry, Roskilde University Center
- 1978-1979: Various soft money positions, scholarships and teaching positions
- 1977-1978: Mandatory civil service
- 1973-1977: Instructor at Institute of Biochemistry and Zoological Laboratory, University of Copenhagen

Publications:

5 recent publications relevant to this proposal:

Kiørboe, T. & A. W. Visser, 1999. Predator and prey perception in copepods due to hydromechanical signals. Mar. Ecol. Prog. Ser., **179**: 81-95

Kiørboe, T, E. Saiz & A.W. Visser, 1999. Hydrodynamic signal perception in the copepod *Acartia tonsa*. Mar. Ecol. Prog. Ser., **179**: 97-111.

Kiørboe, T., 2000. Colonisation of marine snow aggregates by invertebrate zooplankton: abundance, scaling, and possible role. Limnol. Oceanogr., **45**: 479-484.

Kiørboe, T., H. Plough & U.H. Thygesen. 2001 Fluid motion and solute distribution around sinking aggregates. I. Small-scale fluxes and heterogeneity of nutrients in the pelagic

Kiørboe, T. & G.A. Jackson. 2001. Marine snow, organic solute plumes, and optimal chemosensory behaviour of bacteria. Limnol. Oceanogr., submitted

5 other significant publications:

Kiørboe, T., F. Møhlenberg & K. Hamburger, 1985. Bioenergetics of the planktonic copepod *Acartia tonsa*: relation between feeding, egg production and respiration, and the composition of specific dynamic action. Mar. Ecol. Prog. Ser. **26**: 85-95.

Kiørboe, T., K.P. Andersen & H. Dam, 1990. Coagulation efficiency and aggregate formation in marine phytoplankton. Mar. Biol. **107**: 235-245.

Kiørboe, T. & E. Saiz, 1995. Planktivorous feeding in calm and turbulent environments with emphasis on copepods. Mar. Ecol. Prog. Ser., **122**: 135-145.

Kiørboe, T. & B.R. MacKenzie, 1995. Turbulence-enhanced prey encounter rates in larval fish: effects of spatial scale, Larval behaviour and size. J. Plankton Res., **16**: 2319-2331.

Kiørboe, T., P. Tiselius, B. Mitchell-Innes, J.L.S. Hansen, A.W. Visser & X. Mari, 1998. Intensive aggregate formation but low vertical flux during an upwelling induced diatom bloom. Limnol. Oceanogr., **43**:104-116.

Synergistic activities:

- 10 years of formal teaching at Universities and regularly lecturing and organizing summer schools at universities in DK and abroad, despite no formal teaching obligations
- Producing material (videos, CDs) for popular scientific TV productions

Collaborators & Other affiliations:

- *Collaborators (co-authors) during past 48 month*: Hans-Peter Grossart (Univ Oldenburg, Germany), Andrew Hirst (Heriot-Watt Univeresity, UK), George Jackson (Univ. Texas A&M, USA), Helle Ploug (University of Copenhagen), Hiroaki Saito (Hokkaido National Fisheries Research Institute, Japan), Enric Saiz (CSIC, Barcelona, Spain) plus collegues at my own institution.
- *Graduate and postdoctoral advisors*: none
- *Thesis advisor and post-graduate sponsor during past 5 years*: Postdocs – K. Tang (univ. Connecticut, USA), H. Saito (Hokkaido National Fisheries Research Institute, Japan), B.R. MacKenzie (McGill University, Canada), M. Viitasalo (Univ. Helsinki, Finland). S. Jonasdottir (SUNY, USA), M. Sabatini (INIDEP, Argentina), P. Caparroy (Univ. Paris, France). Ph.d. students – J. Titelman, H.J. Jakobsen, L.J.S. Hansen, X. Mari, C. Svensen, S. Green. Total of 20 Masters, 10 Ph.D. students , and 9 post-docs advised.

BIOGRAPHICAL SKETCH

Name:	Timothy John Pedley
Address:	D.A.M.T.P., University of Cambridge Silver Street, Cambridge CB3 9EW, U.K.
e-mail:	<t.j.pedley@damtp.cam.ac.uk>
Phone:	Voice (+44) 1223 339842; Fax (+44) 1223 312984
URL:	<http://www.damtp.cam.ac.uk/user/bioguest/tjp3.html>

A. PROFESSIONAL PREPARATION

B.A.:	1963, University of Cambridge
M.A., Ph.D.:	1967, University of Cambridge
Dissertation:	"Plumes, bubbles and vortices"
Postdoctoral work:	1966 - 1968, The John Hopkins University, Dept. of Mechanics
Sc.D.:	1982, University of Cambridge
F.R.S. (Fellow of the Royal Society of London):	1995
Foreign Associate, U.S. National Academy of Engineering:	1999

B. APPOINTMENTS

2000 - present	Head of Department, Department of Applied Mathematics and Theoretical Physics (D.A.M.T.P.), University of Cambridge
1996 - present	G. I. Taylor Professor of Fluid Mechanics, D.A.M.T.P., University of Cambridge
1990 - 1996	Professor of Applied Mathematics, Leeds University
1973 - 1989	Lecturer, then Reader (1989), D.A.M.T.P., University of Cambridge
1968 - 1973	Lecturer, Physiological Flow Studies Unit and Dept. of Mathematics, Imperial College, London

C. PUBLICATIONS

(FIVE MOST RELEVANT)

1. Jones, M.S., Le Baron, L. and Pedley, T.J. 1994. Biflagellate gyrotaxis in a shear flow. *J. Fluid Mech*., **281:** 137-157.
2. Ayaz, F. and Pedley, T.J. 1999. Flow through and particle interception by an infinite array of closely-spaced circular cylinders. *Eur. J. Mech., B (Fluids)*, **18:** 173-196.
3. Vladimirov, V.A., Denissenko, P.V., Pedley, T.J., Wu, M. and Moskalev, I.S. 2000. Algal motility measured by a laser based tracking method. *Marine & Freshwater Res*., **51:** 589-600.
4. Lewis, D.M. and Pedley, T.J. 2000. Planktonic contact rates in homogeneous isotropic turbulence: theoretical predictions and kinematic simulations. *J. Theor. Biol*., **205:** 377-408.
5. Lewis, D.M. and Pedley, T.J. 2001. The influence of turbulence on plankton predation strategies. *J. Theor. Biol.*, **210**: 347-365.

(FIVE ADDITIONAL)

6. Pedley, T.J. & Kessler, J.O. 1992. Hydrodynamic phenomena in suspensions of swimming micro-organisms. *Ann. Rev. Fluid Mech*., **24**: 313-358.
7. Pedley, T.J., Brook, B.S. and Seymour, R.S. 1996. Blood pressure and flow rate in the giraffe jugular vein. *Phil. Trans. R. Soc. Lond. B*, **351**: 855-866.
8. Hillesdon, A.J. and Pedley T.J. 1996. Bioconvection in suspensions of oxytactic bacteria: linear theory. *J. Fluid Mech*., **324:** 223-259.
9. Pedley, T.J. and Hill, S.J. 1999. Large amplitude undulatory fish swimming: fluid mechanics coupled to internal mechanics. *J. exp Biol.***, 202:** 3431-3438.
10. Bearon, R.N. and Pedley, T.J. 2000. Modelling run-and-tumble chemotaxis in a shear flow. *Bull. Math. Biol.*, **62:** 775-791.

D. SYNERGISTIC ACTIVITIES (FIVE OF MANY; SELECTED FOR DIVERSITY)

Editor, Journal of Fluid Mechanics, 2000 - present (Associate Editor 1983 - 2000)

Member, Executive of Congress Committee, International Union of Theoretical and Applied Mechanics, 1996 - present (Secretary 2000 - present)

Member, World Council for Biomechanics, 1990 - present

President, Mathematical Sciences Section, British Association for the Advancement of Science, 1996-7

Chairman, Society for Experimental Biology Symposium "Biological Fluid Dynamics", Leeds, 1994

E. COLLABORATORS & OTHER AFFILIATIONS

COLLABORATORS (MAJOR)
R.D. Kamm (M.I.T.)
J.O. Kessler (Univ. of Arizona)
C.D. Bertram (Univ. of New South Wales)
X.Y. Luo (Univ. of Sheffield)
V.A. Vladimirov (Univ. of Hull)

GRADUATE AND POSTDOCTORAL ADVISORS
Prof. G.K. Batchelor (Cambridge)
Prof. O.M. Phillips (Johns Hopkins)
Prof. Sir James Lighthill (London and Cambridge)

POSTDOCTORAL ASSOCIATES (WITH CURRENT AFFILIATION)
C.D. Bertram (Univ. of New South Wales)
O.R. Tutty (Univ. of Southampton)
N.A. Hill (Univ. of Glasgow)
M.P. Rast (Univ. of Colorado)
E.O. Carew (Cleveland Clinic)
J. Cheng (Univ. of Delaware)
T. Chou (UCLA)
S.L. Waters (Univ. of Nottingham)
K.D. Stephanoff (Lehigh Univ.)
M.E. Ralph (private consulting)
T.W. Lowe (RCMS Shrivenham)
P.E. Hydon (Univ. of Surrey)
X.Y. Luo (Univ. of Sheffield)
M. Heil (Univ. of Manchester)
D.M. Lewis (Univ. of Reading)
A.M. Metcalfe (Univ. of Cambridge)

PAST PH.D. STUDENTS
London: S.G. Springer (1973).

Cambridge: I.J. Sobey (1976), S.P. Farthing (1977), T.W. Secomb (1979), S.J. Cowley (1981), G.K. Aldis (1983), M.S. Borgas (1986), C.G. Phillips (1987), P.C. Matthews (1989), C.M. Kenyon (1989), O.E. Jensen (1990), P.E. Hydon (1991), A.L. Hazel (1998), J.C. Guneratne (1999), R.N. Bearon (2001), V. Magar (2001).

Leeds: A.J. Hillesdon (1994), F. Ayaz (1995), M.S. Jones (1995), M. Heil (1995), D.G. Lynch (1996), S.L. Waters (1996), B.S. Brook (1997), A.M. Metcalfe (1998), S.J. Hill (1998).

ANDRÉ WILLIAM VISSER
Curriculum Vitae

Biographical:
Date of Birth: August 8, 1957
Place of Birth: Wellington, New Zealand
Citizenship: New Zealand and Netherlands

Present Position: Senior Scientist, Danish Institute for Fisheries Research, Department of Marine Ecology and Aquaculture, Charlottenlund, Denmark.

Education:
1979 B.Sc., Physics, Victoria University of Wellington, New Zealand.
1980 B.Sc.(hon), Physics, Victoria University of Wellington, New Zealand.
1983 M.Sc., Physics, Victoria University of Wellington, New Zealand.
1989 Ph.D., Coastal Oceanography, State University of New York at Stony Brook, USA.
1991-93 post doc: Regions of Freshwater Influence, Institute for Marine and Atmospheric Research, Utrecht University, Utrecht, the Netherlands

Previous Positions:
1991–95 Research Associate, Institute for Marine and Atmospheric Research, Utrecht University, Utrecht, the Netherlands.
1989–91 Professor (Titular), Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California, Ensenada, México.
1989 Adjunct Assistant Professor, Marine Operations and Research, Long Island University, Southampton, New York.

Publications: 25 peer-reviewed articles in international journals and books and over 30 articles and reports of non-reviewed nature. Most recent publications relevant to project.

Visser, AW, 2001. Hydromechanical signals in the plankton. *Marine Ecology Progress Series*. **222:** *1-24*.
Visser, AW and PR Jonsson, 2000. On the reorientation of non-spherical prey particles in a feeding current. *Journal of Plankton Research*. **22:** *761-777*.
Kiørboe, T. and AW Visser, 1999. Predator and prey perception in copepods due to hydromechanical signals. *Marine Ecology Progress Series,* **179:** *81-95*.
Visser, AW & BR MacKenzie, 1998. Turbulence induced contact rates of plankton: the question of scale. *Marine Ecology Progress Series,* **166:** *307-310*.
Visser, AW, 1997. Using random walk models to simulate the vertical distribution of particles in a turbulent water column. *Marine Ecology Progress Series* **158:** *275-281*.

Other significant publications:

Visser, AW, Saito H, Saiz E, Kiørboe T. 2002. Turbulence and zooplankton production: Insights from PROVESS. *J. Sea Res* accepted

Visser, AW, H Saito, E Saiz & T Kiørboe, 2001. Observations of copepod feeding and vertical distribution under natural turbulent conditions in the North Sea. *Marine Biology* **138:** 1011-1019.

Richardson, K, AW Visser & F Bo Pedersen, 2000. Subsurface phytoplankton blooms fuel pelagic production in the North Sea. *Journal of Plankton Research.* **22:** 1663-1671.

Visser, AW & S. Jónasdóttir, 1999. Lipids, buoyancy and the seasonal vertical migration of *Calanus finmarchicus*. *Fisheries Oceanography.* **8** (suppl 1): *100-106.*

Visser, AW, 1994. On tidal rectification, friction and geostrophic degeneracy. *Journal of Physical Oceanography,* **24:** *2196–2200.*

Synergistic activities:

- Teaching of several university courses at Long Island University, Universidad Autónoma de Baja California, Utrecht University, Copenhagen University, as well as 2 European Community summer schools under the MAST program.
- Popular articles on marine life and turbulence, climate and fisheries, and hydrodynamic modelling in Danish publications aimed at the general public.

Collaborators & Other affiliations:

- Collaborators (co-authors) during past 48 month: John H. Simpson, Tom Rippith (School of Ocean Sciences, Menai Bridge, UK), Jürgen Sündermann, Hans Burchard (Institut für Meereskunde,Universität Hamburg, Germany), John Huthnance, John Howarth (Proudman Oceanographic Lab, Bidston Observatory, UK), Julie Piertzak (Technical University Delft, Netherlands), Hans van Haren (Netherland Institue for Sea Research, Texel, Netherlands), Katherine Richardson (Aarhus University, Denmark), Per Jonsson (University of Gothenberg, Sweden), Hiroaki Saito (Hokkaido National Fisheries Research Institute, Japan), Enric Saiz (CSIC, Barcelona, Spain), Thomas Kiørboe, Brian MacKenzie, Sigrun Jónasdóttir, Uffe Thygesen (Danish Institute for Fisheries Research, Charlottenlund, Denmark)
- Graduate and postdoc advisors:Malcolm Bowman (State University of New York, Stony Brook), Wil de Ruijter (University of Utrecht, Netherlands)
- Thesis advisor and post-graduate sponsor: none during past 5 years, althtough 3 MS, 1 PhD and 2 post docs prior to that, at Utrecht University, the Netherlands.

Biographical Sketch

DANIEL GRUNBAUM
Assistant Professor, School of Oceanography
University of Washington, Seattle, WA 98195-7940
Phone: (206) 221-6594 Fax: (206) 543-6073
email: grunbaum@ocean.washington.edu

A. Professional Preparation:

University of Washington, Seattle, WA.	Mechanical Engineering	B. S. 1983.
University of Washington, Seattle, WA.	Mechanical Engineering,	M.S. 1986.
Cornell University, Ithaca, NY.	Ecology and Evolutionary Biology	Ph.D. 1992.

Research Associate, Department of Zoology, University of Washington. Advisor: Thomas L. Daniel, 1992-1993.

B. Appointments:

Assistant Professor	Oceanography, University of Washington	2000-
Research Assistant Professor	Zoology, University of Washington	1998-2000
Visiting Assist. Prof.	Mathematics, University of Utah	1995-97.
Killam Fellow	Mathematics, University of British Columbia	1993-95.

C. Five related publications:

Grünbaum, D., D. Eyre, and A. Fogelson (1998) "Functional geometry of ciliated tentacular arrays in active suspension feeders." J. Exp. Biol. 201:2575-2589.

Grünbaum, D. (1997) "Hydromechanical mechanisms of colony organization and cost of defense in an encrusting bryozoan, *Membranipora membranacea*," Limnol. Ocean. 42(4):741-752.

Grünbaum, D. (1995) "A model of feeding currents in encrusting bryozoans shows interference between zooids within a colony," J. Theor. Biol. 174:409-425.

Flierl, G., D. Grünbaum, S. Levin, and D. Olson (1999) "Individual-based perspectives on grouping." J. Theor. Biol. 196:397-454.

Grünbaum, D. (2002) “Predicting availability to consumers of spatially and temporally variable resources.” Hydrobiologia, in press.

Five additional publications:

Grünbaum, D. (2000) "Advection-diffusion equations for internal state-mediated random walks" SIAM Journal on Applied Mathematics . 61(1):43-73.

Grünbaum, D. (1999) "Advection-diffusion equations for generalized tactic searching behaviors," J. Math. Biol. 38:169-194.

Grünbaum, D. (1998) "Using spatially-explicit models to characterize foraging performance in heterogeneous landscapes," Amer. Nat. 151(2):97-115.

Grünbaum, D. (1994) "Translating stochastic density-dependent individual behavior to a continuum model of animal swarming", J. Math. Biol. 33:139-161.

Rohani, P., T.J. Lewis, D. Grünbaum, and G.D. Ruxton (1997) "Spatial self-organization in ecology: pretty patterns or robust reality?", TREE 12(2):70-74.

D. Synergistic activities:

Co-Instructor, Larval Ecology, Friday Harbor Labs, U. of Wash., Summer, 2002.

Co-Instructor, Biomechanics & Biophysics of Marine Organisms, Friday Harbor Labs, U. of Wash., Summer, 2000.

Co-Instructor, Chemosensory Ecology, Friday Harbor Labs, U. of Wash., 1999.

Principle Lecturer, Summer Program in Geophysical Fluid Dynamics: Coupling of Biological and Physical Processes, W.H.O.I., Woods Hole, MA, 1994.

Co-Instructor, Biomechanics (Zoology 440), University of Washington, Seattle, WA, Winter 1992,1993.

Supported undergraduates: Tansy Clay Michelangelo Von Dassow

E.i. Collaborators during the last 48 months

Steven Courtney, S.E.I., Portland, OR
Leah Edelstein-Keshet, U. B.C.
Glenn Flierl, M.I.T.
Martha Groom, U. of Washington
Peter Kareiva, U. of Washington
Terrie Klinger, U. of Washington
Julia Parrish, U. of Washington
Mark Willis, U. of Arizona
James Belanger, L.S.U.
Timothy Lewis, U. of Utah
Simon Levin, Princeton
Donald Olson, U. of Miami
Hans Othmer, U. of Utah
Richard Veit, C.U.N.Y. Staten Island
James Watmough, V.P.I.

E.ii. Graduate and Post-Graduate Advisors

Thomas Daniel	University of Washington	Post-doctoral Advisor
Charles Greene	Cornell University	PhD Committee
C. Drew Harvell	Cornell University	PhD Committee
Simon Levin	Princeton University	PhD Advisor
Leah Edelstein-Keshet	U.B.C.	Post-doctoral Advisor
James J. Riley	University of Washington	Masters Advisor

E.iii. PhD student in progress:

Suzanne Menden-Deuer

Committee member for past and present PhD students

Stacey Combes Kevin Flick Erica Goldman Winnie Lau Alan Trimble
Mark Scheuerell Jennifer Staver Kristin Sherrard (U Chicago) Cory Samuels

Post-docs:

Steven Viscido Alan Trimble

CURRICULUM VITAE
(abbreviated)

James J. Riley

January, 2002

General biographical information

Rank: Professor, Mechanical Engineering
Adjunct Professor, Applied Mathematics

Professional Preparation:
Undergraduate Institution: Rockhust College, Physics, A.B., 1965
Graduate Institution: The Johns Hopkins U., Mechanics, Ph.D., 1972
Posdoctoral Institution: National Center for Atmospheric Research, 1972-1973

Experience:
Acting Chair, Mechanical Engineering, U of W, 1997 to 1999
Professor, Mechanical Engineering, U of W, 1985 to present
Adjunct Professor, Applied Mathematics, U of W, 1985 to present
Associate Professor, Mechanical Engineering, U of W,1983 to 1985
Department Manager and Program Manager, Flow Industries, Inc., 1977 to 1983
Senior Research Scientist, Flow Industries, Inc., 1975 to 1983
Research Scientist, Flow Industries, Inc., 1973 to 1975
Research Physicist, Naval Research Laboratory, 1972 to 1973
Chaire de Mathematiques Industrielles, l'Universite Joseph Fourier, Grenoble, France, 1989 to 1992, (visiting chaired position)

5 Closely-Related Recent Publications:

de Bruyn Kops, S. M., and J. J. Riley. 1998. "Direct numerical simulation of laboratory experiments in isotropic turbulence", Phys. Fluids, Vol. 10(9), pp. 2125-2127.

Slinn, D. N., and J. J. Riley. 1998. "A model for the simulation of turbulent boundary layers in an incompressible stratified flow", J. Comp. Phys., Vol. 144, pp. 550-602.

Slinn, D. N., and J. J. Riley. 1998. "Turbulent dynamics of a critically reflecting internal gravity wave", Theoret. Comp. Fl. Dyn., Vol. 11, pp. 281-303.

de Bruyn Kops, S. M., and J. J. Riley. 2000. "Re-examining the thermal mixing layer with numerical simulations", Phys. Fluids, Vol. 12, pp. 185-192.

Riley, J. J., and M.-P. Lelong. 2000. "Fluid Motions in the presence of strong stable stratification", Ann. Rev. Fluid Mech., (invited article), Vol. 32, pp. 613-657.

5 Other Significant Recent Publications:

Montgomery, C. J., G. Kosaly, and J. J. Riley. 1997. "Direct numerical simulation of turbulent nonpremixed combustion with multistep hydrogen-oxygen kinetics", Comb. Flame, Vol. 109, pp. 113-144.

Cook, A. W., and J. J. Riley. 1998. "Subgrid-scale modeling for turbulent, reacting flows", Comb. Flame, Vol. 112, pp. 593-606.

de Bruyn Kops, S. M., J. J. Riley, and G. Kosaly. 2001. "Direct numerical simulation of reacting scalar mixing layers", Phys. Fluids, Vol. 13, pp. 1450-1465.

de Bruyn Kops, S. M., and J. J. Riley. 2001. "Mixing models for large-eddy simulation of non-premixed turbulent combustion", J. Fluids Engr. - T. ASME, Vol. 123(2), pp. 341-346.

Yanase, S., M. Mizuguchi, J. J. Riley. 2001. "Rotating magnetohydrodynamic free-shear flows. I. Linear stability analysis", Phys. Fluids, Vol. 13(7), pp. 1946-1955.

Synergistic Activities:

As chair of the Division of Fluid Dynamics of the American Physical Society, Riley helped initiate an effort to develop a multi-media tool to aid in teaching fluid mechanics at the college level. Subsequently in this regard he was the chair of the National Visiting Committee of a grant sponsored by the NSF Division of Undergraduate Education. This has resulted in the publication of a CD-Rom entitled "Multi-Media Fluid Mechanics", Cambridge University Press, which has received excellent reviews from the academic community, and is beginning to be used extensively in the classroom. He is now actively involved in the development of a second CD-Rom in this series, again funded by the NSF Division of Undergraduate Education, and to be distributed by Cambridge University Press.

Riley developed the equations of motion for low Reynolds number, spherical particles in turbulent flows (Riley, Ph.D. thesis, 1972; Maxey and Riley, Phys. Fluids, 1983); subsequently he developed the methodology and was the first to perform direct numerical simulations of low Reynolds number particle motion in turbulent flows (Riley and Patterson, Phys. Fluids, 1974).

Riley developed the methodology and was the first to perform direct numerical simulations of turbulence is stably-stratified fluids, including homogeneous turbulence (Riley, Metcalfe and Weissman, in "Nonlinear Properties of Internal Waves", AIP, 1981) and shear flow turbulence (Staquet and Riley, Dyn. Atmos. Oceans, 1989). In addition to the computational results, this work led to theoretical concepts which have proven very useful in interpreting turbulence in stably-stratified fluids.

Collaborators and Other Affiliations:

Collaborators:
- S. M. de Bruyn Kops, U. Mass. Amherst
- G. Kosaly, U. Wash., Mech. Eng.
- J. C. Kramlich, U. Wash., Mech. Eng.
- I.-Y. Shen, U. Wash., Mech. Eng.
- A. W. Cook, Lawrence Livermore National Laboratory
- D. N. Slinn, University of Florida
- M.-P. Lelong, Northwest Research Associates
- K. Winters, U. Wash., Applied Physics Lab.

Graduate Advisor:
- S. Corrsin (deceased)

Thesis Advisor:
- Total number of students as Ph.D. thesis advisor: 14
- Total number of postdoctoral fellows as advisor: 4

STEVEN T. Wereley, PH.D.
Assistant Professor, Mechanical Engineering, Purdue University
Phone: (765) 494-5624 email: wereley@purdue.edu
Fax: (765) 494-0539 http://widget.ecn.purdue.edu/~swereley

Research Interests
Professor Wereley completed his masters and doctoral research at Northwestern University studying Taylor-Couette flows as filtration aids. He joined the Purdue University faculty in August of 1999 after a two-year postdoctoral appointment at the University of California Santa Barbara in the Department of Mechanical and Environmental Engineering. During his time at UCSB he focused exclusively on developing diagnostic techniques for microscale systems, work which ultimately led to a dozen conference and journal papers as well as a patent. His current research interests include designing and testing microfluidic MEMS devices, investigating biological flows at the cellular level, improving micro-scale laminar mixing, and developing new microfluidic diagnostic techniques. Professor Wereley is very active in the field of microscale fluid mechanics, delivering invited lectures and consulting, in addition to performing scholarly research in the area. He is a member of the American Physical Society, the American Institute of Aeronautics and Astronautics, and the American Society of Mechanical Engineers.

a. Professional Preparation

Lawrence University, Appleton, WI	Physics	B.A. 1990
Washington University, St. Louis, MO	Mechanical Engineering	B.S. 1990
Northwestern University, Evanston, IL	Mechanical Engineering	M.S. 1992
Northwestern University, Evanston, IL	Mechanical Engineering	Ph.D. 1997
University of California, Santa Barbara, CA		
Post Doctoral Scholar	Experimental Microfluidics	1997-1999

b. Appointments

8/1999-Present **Purdue University**, West Lafayette, IN
Assistant Professor of Mechanical Engineering

c. Publications

5 Related Publications

R. Gomez, R. Bashir, A. Sarakaya, M.R. Ladisch, J. Sturgis, J.P. Robinson, T. Geng, A.K. Bhunia, H.L. Apple, and S.T. Wereley, "Microfluidic Biochip for Impedance Spectroscopy of Biological Species," J. Biomedical Microdevices, Vol. 3, No. 3, 201-209 (2001).

C.D. Meinhart, J.G. Santiago, R.J. Adrian, and S.T. Wereley, "Micron Resolution Particle Image Velocimeter," US Patent Applied For, December, 1999.

S.T. Wereley and R.M. Lueptow, "Inertial particle motion in a Taylor Couette rotating filter," Phys. Fluids, Vol. 11, No. 2, 325-333, (1999).

S.T. Wereley and R.M. Lueptow, "Spatio-temporal character of nonwavy and wavy Taylor Couette flow," J. Fluid Mech. Vol. 364, 59-80, (1998).

J.G. Santiago, S.T. Wereley, C.D. Meinhart, D. Beebee, and R.J. Adrian, "A particle image velocimetry system for microfluidics," Exp. Fluids, **Vol. 25**, No. 4, 316-319, (1998).

5 Other Papers

S.W. Stone, C.D. Meinhart, and S.T. Wereley, "A Microfluidic-based Nanoscope," Exp. Fluids (2002), *in press*.

C.D. Meinhart, S.T. Wereley, M.H.B. Gray, "Volume illumination for two-dimensional particle image velocimetry," Meas. Sci. Tech., **Vol. 11**, 809-814, (2000).

C.D. Meinhart, S.T. Wereley, and J.G. Santiago, "Micron-Resolution Velocimetry Techniques," *Developments in Laser Techniques and Applications to Fluid Mechanics*, R. J. Adrian et al. (Eds.), Springer-Verlag, Berlin, pp. 57-70, (2000).

S.T. Wereley and R.M. Lueptow, "Velocity field for Taylor-Couette flow with an axial flow," Phys. Fluids, Vol. 11, No. 12, 3637-3649 (1999).

S.T. Wereley and R.M. Lueptow, "Azimuthal velocity in supercritical circular Couette flow," Exp. Fluids, Vol. 18, pp. 1-9, (1994).

d. Synergistic Activities

1. Member of Center for Bio-Sprays, an interdisciplinary team of 18 colleagues at Purdue in Engineering, Chemistry, Pharmacy, and Veterinary Medicine.
2. Member of Center for Nanoscale Electronics/Biological Devices, an interdisciplinary team of 15 personnel at Purdue and other universities from nearly every field of engineering as well as Medicinal Chemistry, Physics, and Medicine.
3. Member of Integrated Detection of Hazardous Materials team, a Department of Defense project managed jointly by the Center for Sensing Science and Technology, Purdue University and the Naval Surface Warfare Center, Crane, Indiana.
4. Developed a Particle Image Velocimetry (PIV) software package that is currently used in several universities and industrial settings.

e. Collaborators and Affiliations

(i) *Collaborators*

Purdue University: Heather Apple, Rashid Bashir, A.K. Bhunia, Stuart Bolton, George Chiu, T. Geng, Lichuan Gui, Steve Frankel, Rafael Gomez, Mike Ladisch, Mike Plesniak, J.P. Robinson, A. Sarakaya, Paul Sojka, J. Sturgis; **UC Santa Barbara**: Rich Chiu, Mike Gray, Carl Meinhart, Shannon Stone; **Stanford**: Shankar Devasenathipathy, Juan Santiago; **Northwestern University**: Rich Lueptow; **University of Illinois**: Ron Adrian; **University of Wisconsin**: Dave Beebe

(ii) *Graduate Advisors and Postdoctoral Sponsors*

M.S. and Ph.D. advisor: Rich Lueptow, Northwestern University
Postdoctoral Sponsor: Carl Meinhart, UC Santa Barbara

(iii) *Thesis Advisor and Postgraduate-Scholar Sponsor*

Professor Wereley is currently advising 5 Masters students, 2 Ph.D. students, and 1 postdoctoral scholar

M.S. Jinhua Cao, Pramod Chamarthy, Ratnakar Karru, Ira Whitacre, Yabin Zhao
Ph.D. Sang-Youp Lee, Jaesung Jang, **Post doc.** Lichuan Gui

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Maine

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Peter A Jumars

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Peter A Jumars - Professor	0.00	0.00	1.00	$ 9,879	$
2. Lee Karp-Boss - Res. Asst. Prof.	3.60	0.00	0.00	18,058	
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	3.60	0.00	1.00	27,937	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1.50	0.00	0.00	3,625	
3. (0) GRADUATE STUDENTS				0	
4. (2) UNDERGRADUATE STUDENTS				6,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				37,562	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				10,415	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				47,977	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) Data and Web Server $ 3,750 Magnifying PIV System 42,500					
TOTAL EQUIPMENT				46,250	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				1,500	
2. FOREIGN				4,300	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				9,535	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				800	
5. SUBAWARDS				0	
6. OTHER				2,050	
TOTAL OTHER DIRECT COSTS				12,385	
H. TOTAL DIRECT COSTS (A THROUGH G)				112,412	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Tot less D (Rate: 47.0000, Base: 66162)					
TOTAL INDIRECT COSTS (F&A)				31,096	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				143,508	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 143,508	$

M. COST SHARING PROPOSED LEVEL $ 99,786 AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Peter A Jumars

ORG. REP. NAME*
James ward

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

0219773

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION University of Maine	FOR NSF USE ONLY				
	PROPOSAL NO.	DURATION (months) Proposed	Granted		
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Peter A Jumars	AWARD NO.				

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Peter A Jumars - Professor	0.00	0.00	2.00	$ 20,746	$
2. Lee Karp-Boss - Res. Asst. Prof.	3.60	0.00	0.00	18,960	
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	3.60	0.00	2.00	39,706	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1.50	0.00	0.00	3,806	
3. (0) GRADUATE STUDENTS				0	
4. (2) UNDERGRADUATE STUDENTS				6,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				49,512	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				14,359	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				63,871	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				1,500	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 10,000 2. TRAVEL 150 3. SUBSISTENCE 1,760 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (2) TOTAL PARTICIPANT COSTS				11,910	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				8,335	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				800	
5. SUBAWARDS				0	
6. OTHER				1,450	
TOTAL OTHER DIRECT COSTS				11,585	
H. TOTAL DIRECT COSTS (A THROUGH G)				88,866	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Tot less D&F (Rate: 47.0000, Base: 76957)					
TOTAL INDIRECT COSTS (F&A)				36,170	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				125,036	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 125,036	$

M. COST SHARING PROPOSED LEVEL $ 24,713 AGREED LEVEL IF DIFFERENT $

PI/PD NAME Peter A Jumars	FOR NSF USE ONLY		
	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* James ward	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

0219773

SUMMARY PROPOSAL BUDGET

YEAR 3

	FOR NSF USE ONLY		
ORGANIZATION: **University of Maine**	PROPOSAL NO.	DURATION (months)	
		Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Peter A Jumars**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Peter A Jumars - Professor	0.00	0.00	2.00	$ 21,783	$
2. Lee Karp-Boss - Res. Asst. Prof.	3.60	0.00	0.00	19,909	
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	3.60	0.00	2.00	41,692	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1.50	0.00	0.00	3,997	
3. (0) GRADUATE STUDENTS				0	
4. (2) UNDERGRADUATE STUDENTS				6,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				51,689	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				15,077	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				66,766	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,500	
2. FOREIGN				4,300	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 7,000					
2. TRAVEL 1,000					
3. SUBSISTENCE 2,180					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (7) TOTAL PARTICIPANT COSTS				10,180	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				8,335	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				800	
5. SUBAWARDS				0	
6. OTHER				2,250	
TOTAL OTHER DIRECT COSTS				12,385	
H. TOTAL DIRECT COSTS (A THROUGH G)				96,131	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) Tot less D&F (Rate: 47.0000, Base: 85950)					
TOTAL INDIRECT COSTS (F&A)				40,397	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				136,528	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 136,528	$

M. COST SHARING PROPOSED LEVEL $ 25,949 AGREED LEVEL IF DIFFERENT $

	FOR NSF USE ONLY		
PI/PD NAME: **Peter A Jumars**	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*: **James ward**	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

0219773

SUMMARY PROPOSAL BUDGET — Cumulative

FOR NSF USE ONLY

ORGANIZATION: University of Maine				PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Peter A Jumars				AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Peter A Jumars - Professor	0.00	0.00	5.00	$ 52,408	$
2. Lee Karp-Boss - Res. Asst. Prof.	10.80	0.00	0.00	56,927	
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	10.80	0.00	5.00	109,335	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (3) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	4.50	0.00	0.00	11,428	
3. (0) GRADUATE STUDENTS				0	
4. (6) UNDERGRADUATE STUDENTS				18,000	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				138,763	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				39,851	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				178,614	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 46,250					
TOTAL EQUIPMENT				46,250	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				5,500	
2. FOREIGN				8,600	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 17,000 2. TRAVEL 1,150 3. SUBSISTENCE 3,940 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (9) TOTAL PARTICIPANT COSTS				22,090	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				26,205	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				2,400	
5. SUBAWARDS				0	
6. OTHER				5,750	
TOTAL OTHER DIRECT COSTS				36,355	
H. TOTAL DIRECT COSTS (A THROUGH G)				297,409	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				107,663	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				405,072	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 405,072	$

M. COST SHARING PROPOSED LEVEL $ 150,448 — AGREED LEVEL IF DIFFERENT $

PI/PD NAME: Peter A Jumars	FOR NSF USE ONLY		
	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*: James ward	Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

0219773

F BUDGET JUSTIFICATION

University of Maine

PERSONNEL

Pete Jumars will coordinate the components of this proposal, *i.e.,* experimental design (all senior personnel, including our English and Danish collaborators) modeling in Seattle (Grünbaum and Riley), design, fabrication and calibration at Purdue (Wereley), measurement at UMaine and analysis at all four locations. He will participate personally in the Couette runs, PIV data analysis in the context of the singularity models and publication. These efforts account for the request of 1 mo yr^{-1}, which is a very conservative estimate of the time that he will spend. In addition, aided by a TA from each of the University of Washington and Purdue components, he will take primary responsibility for the development of teaching materials and teacher workshops in years two and three, respectively, accounting for the additional 1-mo request in each of those years. He will also take primary responsibility for getting data, models and teaching materials on the web server. Jumars has long experience coordinating interdisciplinary work. For example, he was the responsible program officer at ONR for the HEBBLE program in FY82. In 1991 he organized the proposal and for 1992-1993 was the first Acting Director for the University of Washington's University Research Initiative on Bioremediation. He maintained the web pages of the biological oceanography faculty at the University of Washington for several years, and has taken major responsibility for gradual re-organization of the School of Marine Sciences web site at UMaine (*e.g.,* <http://www.ume.maine.edu/~marine/clusters.html>). He has used web-assisted teaching since 1995, including an interactive, multi-draft course on scientific writing.

Lee Karp-Boss will have primary responsibility for culture selection (although Bob Andersen at the Bigelow Laboratory for Ocean Sciences has already helped us in selecting target taxa and is enthusiastic about our potential contribution to understanding of functional morphology). Most importantly, she will be in charge of all the Couette runs with phytoplankton and of culturing the cells for this work and will take primary responsibility for data analysis. Accordingly, Karp-Boss will spend 6 mo yr^{-1} on this project. UMaine will cost share at 40%, so only 3.6 mo yr^{-1} are requested from NSF. Karp-Boss has extensive experience with phytoplankton culturing and with Couette experiments. She also has conducted postdoctoral experiments with Pedro Verdugo at the University of Washington on dynamics of phytoplankton-derived gels in Couette flows. Most recently, she has been acquiring further breadth in phytoplankton ecology through participation in field programs with Pat Wheeler at OSU. Karp-Boss has accepted a research position at UMaine, effective 1 March 2002.

It is crucial that we have a geometrically accurate representation of the solid surface of the phytoplankton cells that we study rather than of a cell grown under some other conditions at some other time. Thus we are fortunate to have the help of Kevin Eckelbarger, who has agreed to oversee our SEM studies of the morphology of our target species. Eckelbarger has extensive experience that is essential in keeping artifacts to a minimum. He will teach Karp-Boss, Shellito and Jumars in these methods, oversee their SEM work and do selected specimens for comparison and calibration. Eckelbarger is on a full-time administrative salary and therefore requests no salary.

Shawn Shellito, a Research Technician, at 1.5 mo yr^{-1}, will help with routine culture, equipment maintenance and SEM preparation. He is resident at the Darling Marine Center, whereas Karp-Boss will come for extended periods of experiments from the location of her primary appointment in Orono. Note that no graduate research assistants are proposed, but we have asked for support to engage two undergraduates each summer in this work. Jumars has had two undergraduate interns in his laboratory each summer at UMaine (2000 and 2001); all are in graduate school of plan to enter graduate school in aspects of oceanography, ecology or engineering. This project offers superb opportunities for undergraduates to gain skills in math, physics and biomechanics as they help us with the effort. And the interns provide substantial assistance. For example, Rachel Schwartz (an intern from Bryn Mawr) made enough progress to present her results as first author (poster) at ASLO in Albuquerque (February 2001), and they have driven much of the laboratory's work during summer 2001.

CAPITAL EQUIPMENT

$122,500 in capital equipment purchases are proposed, but > 62% of that expense is borne as cost sharing by UMaine. As part of Jumars' startup package, UMaine agreed to cost share at 50% on capital equipment on proposals submitted within 2 yr of his initial appointment (and has extended that agreement to the present proposal). In addition, UMaine has agreed to apply $15k remaining of Jumars' startup package to purchase of the PIV system, whose total cost is $115k. Although systems that require only 1:1 optics (no magnification) can be configured at substantially less cost, our problem demands high resolution. Magnification complicates both hardware and software, driving the cost. Components include a computer/controller, a YAG laser with projection optics to illuminate a planar "sheet" within the Couette, a rapid-recovery, megapixel CCD camera with magnifying optics that is the heart and major expense of the system, and software for control of the camera and lighting, of data acquisition and of data conversion into velocity (fluid) and edge (of the phytoplankter) fields. PIV components will be purchased and assembled under the direction of Steve Wereley (Purdue), who has extensive experience in building specialized PIV systems with high spatial and temporal resolution (*e.g.*: <http://widget.ecn.purdue.edu/~swereley/piv.html>; <http://widget.ecn.purdue.edu/~swereley/nozzle.html>; Wereley & Lueptow 1999a,b; Meinhart *et al*. 2000a,b). He has budgeted time at the Darling Marine Center in 2002 to complete the assembly and debug the system. This participation is absolutely essential; without it the system likely would be outdated before it was completed.

A server is key to our otherwise geographically far-flung collaboration and educational components. It has become routine in collaborations to house data and draft manuscripts at a web site for all to use. The server easily will repay its equivalent in travel costs early in the program. It is unrealistic to expect accommodation of this sort of effort on common-use servers because of the high data volume and large file sizes and frequent transfers and updates, as well as high usage rates by non-UMaine scientists. In addition, we will make freely available on this server all curricular materials for both Jumars' undergraduate class in biological fluid dynamics and for the high-school workshops and outreach. A low-maintenance server (with sufficient capacity for expansion through the program, rapid access and RAID backup currently costs $7,500 (cost shared 50% by UMaine).

TRAVEL:

Domestic travel is primarily for traveling among PI and CoPI labs. In years 2 and 3, it also will support presentation of results at national meetings. In year 3, it includes funds for Jumars to participate in the Friday Harbor course at the same time that he is coordinating work with Grünbaum and Riley. During the first year, we will have a planning meeting of senior participants in late spring at the Darling Center, after we have exchanged detailed plans and protocols. One agenda item will be a tutorial and review of unsteady flow effects at a level well beyond that presented here. Foreign travel is to better engage our foreign partners from the planning stage onward. We have budgeted for travel during planning (yr 1) and during analysis (yr 3). We intend that the trip in yr 3 will include experimental work in Denmark with some of the more specialized apparatus in Kiørboe's laboratory (Kiørboe *et al*. 1999). It should be emphasized that this collaboration is not being started but rather strengthened and expanded to include additional PIs and students. Jumars has co-taught with Kiørboe in a European Union short course on Theoretical Microbial Ecology (October 1998) and did the tutorial on low-***Re*** flows in the session on that topic organized by Kiørboe at Copenhagen 2000 (ASLO meeting). Participation in the proposal by Pedley grew out of interactions arising at that session.

PARTICIPANT SUPPORT COSTS

Two high-school teachers, one from Maine and one from Washington State, will spend a month during summer 2004 in Jumars' laboratory helping to extract and tailor standards-relevant material on low-***Re*** flows. The two teachers will share the stipend, which will allow us to recruit highly qualified candidates with the commitment to follow through. Travel funds in the UMaine budget are for the Maine teacher; Washington State teacher travel is in the U. Washington budget. Subsistence covers both teachers' housing and meal plan at the Darling Center. In summer of 2005, those same two teachers will be leaders (each in their own state) for two intensive, 10-d workshops, one each at the Darling Center and the Friday Harbor Laboratories. For each workshop, 6 other teachers will be recruited from the state where the workshop is held, controlling travel costs, and each teacher will receive a more modest stipend ($1,000). Stipends are included here for the 7 teachers from Maine as are housing and meal plan. (Parallel expenses for the Friday Harbor workshop are in the U. Washington budget.) Maine's Mathematics & Science Teaching Excellence Collaborative (MMSTEC, see appended letter) will help us to recruit qualified teachers. Patricia Morse (Acting Professor, Dept. Zoology, Univ. Washington), familiar with the standards from her tenure at NSF's educational division and subsequent activities (*e.g.,* Morse *et al*. 2001), will assist Grünbaum, who has firm teaching contacts in Seattle schools, in recruiting qualified candidates. She further has offered to serve as a science partner for Seattle and Friday Harbor participants (e-mail correspondence attached).

OTHER DIRECT COSTS

Materials and supplies include culture containers and media, cultures form the Provasoli - Guillard National Center for Culture of Marine Phytoplankton, computer storage media, software updates and tracer particles. We are budgeting $6,400 the first year and $5,700 each subsequent year for fluorescent tracer particles that are essential to the success of the PIV measurements. The particles must be small enough to have negligible history effects of their own, making some way to enhance their detection essential. To make sure that they are in the field of view, the tank must have a moderately dense suspension. Our estimates include filtration to recover and re-use a substantial fraction of these expensive but essential tracers. Wereley currently uses particles that absorb at 532 and emit at 612 nm, making resolution from the 685-nm peak of chlorophyll *a* fluorescence feasible. Also included are $835 per year for EM supplies.

Publication costs are included in years 2 and 3. Computer services are budgeted for networking and troubleshooting at the remote Darling Marine Center. Needs include server setup and maintenance and networking of the data-acquisition system to it.

The category (6) "Other" includes phone ($200 yr^{-1}) and postage ($100 yr^{-1}) for coordination of the project, and shipping is included in year 1 ($600) to send components back to Wereley (Purdue) for repair or modification and in year 3 ($800) to send the large Couette tank to and from Friday Harbor for the teachers' workshop. Modest photocopy costs ($100 yr^{-1}) are anticipated. Small-boat time is budgeted at $1,050 each year, reflecting current costs to maintain and operate the *R/V Nucella* (Darling Marine Center) for five 1-d trips each year. These trips will allow field collection of diatom specimens for isolation and culture. We (Karp-Boss and Jumars) found field isolation necessary to obtain chains. Over many generations, chain-forming ability is often lost in laboratory cultures, perhaps in response to the absence of unsteady shears. We can be efficient at this collection because of near-real-time data acquisition on phytoplankton abundance and morphology in the adjacent (to the Darling Center) Damariscotta River with the "flowCAM" developed and deployed by our colleagues at the Bigelow Laboratories (Sieracki *et al*. 1998 & <http://www.bigelow.org/flowcam/>).

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
University of Washington

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Daniel Grunbaum

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Daniel Grunbaum - Assistant Professor	3.00	0.00	0.00	$ 17,298	$
2. James J Riley - Professor	0.00	0.00	1.00	12,968	
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	3.00	0.00	1.00	30,266	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				23,620	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				53,886	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				8,974	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				62,860	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) Computer $ 2,500					
TOTAL EQUIPMENT				2,500	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				0	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,500	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				7,773	
TOTAL OTHER DIRECT COSTS				9,273	
H. TOTAL DIRECT COSTS (A THROUGH G)				74,633	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 51.6% MTDC (Rate: 51.6000, Base: 64660)					
TOTAL INDIRECT COSTS (F&A)				33,365	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				107,998	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 107,998	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Daniel Grunbaum

ORG. REP. NAME*
Karl valentine

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

1 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

0220284

SUMMARY PROPOSAL BUDGET

YEAR 2

FOR NSF USE ONLY

ORGANIZATION **University of Washington**	PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Daniel Grunbaum**	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Daniel Grunbaum - Assistant Professor	3.00	0.00	0.00	$ 17,991	$
2. James J Riley - Professor	0.00	0.00	1.00	13,487	
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	3.00	0.00	1.00	31,478	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				24,565	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				56,043	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				9,333	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				65,376	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				3,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 1,000 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (1) TOTAL PARTICIPANT COSTS				1,000	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				500	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				8,035	
TOTAL OTHER DIRECT COSTS				9,535	
H. TOTAL DIRECT COSTS (A THROUGH G)				78,911	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 51.6% MTDC (Rate: 51.6000, Base: 70176)					
TOTAL INDIRECT COSTS (F&A)				36,211	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				115,122	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 115,122	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME **Daniel Grunbaum**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Karl valentine**	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

0220284

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION: **University of Washington**			FOR NSF USE ONLY		
			PROPOSAL NO.	DURATION (months)	
				Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Daniel Grunbaum**			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Daniel Grunbaum - Assistant Professor	3.00	0.00	0.00	$ 19,185	$
2. James J Riley - Professor	0.00	0.00	1.00	14,026	
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	3.00	0.00	1.00	33,211	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				25,550	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				58,761	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				9,808	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				68,569	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				3,600	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 7,000					
2. TRAVEL 2,000					
3. SUBSISTENCE 3,200					
4. OTHER 1,050					
TOTAL NUMBER OF PARTICIPANTS (8) TOTAL PARTICIPANT COSTS				13,250	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				500	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				1,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				8,305	
TOTAL OTHER DIRECT COSTS				9,805	
H. TOTAL DIRECT COSTS (A THROUGH G)				95,224	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 51.6 MTDC (Rate: 51.6000, Base: 73969)					
TOTAL INDIRECT COSTS (F&A)				38,168	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				133,392	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 133,392	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME: **Daniel Grunbaum**	FOR NSF USE ONLY		
	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*: **Karl valentine**	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION University of Washington				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Daniel Grunbaum				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. Daniel Grunbaum - Assistant Professor	9.00	0.00	0.00	$ 54,474	$	
2. James J Riley - Professor	0.00	0.00	3.00	40,481		
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0		
7. (2) TOTAL SENIOR PERSONNEL (1 - 6)	9.00	0.00	3.00	94,955		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0		
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0		
3. (3) GRADUATE STUDENTS				73,735		
4. (0) UNDERGRADUATE STUDENTS				0		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				168,690		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				28,115		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				196,805		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)	$		2,500			
TOTAL EQUIPMENT				2,500		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				6,600		
2. FOREIGN				0		
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 7,000 2. TRAVEL 3,000 3. SUBSISTENCE 3,200 4. OTHER 1,050						
TOTAL NUMBER OF PARTICIPANTS (9) TOTAL PARTICIPANT COSTS				14,250		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				2,500		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,000		
3. CONSULTANT SERVICES				0		
4. COMPUTER SERVICES				0		
5. SUBAWARDS				0		
6. OTHER				24,113		
TOTAL OTHER DIRECT COSTS				28,613		
H. TOTAL DIRECT COSTS (A THROUGH G)				248,768		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)						
TOTAL INDIRECT COSTS (F&A)				107,744		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				356,512		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 356,512	$	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					
PI/PD NAME Daniel Grunbaum				FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Karl valentine				Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

Budget Justification

Year 1

Grünbaum (3 mo) and the graduate student (12 mo) will jointly implement the low-Re flow calculations for simple geometries. The technical developments involved in modeling in Year 1 fall generally into three categories: (*i*) development of numerical methods to solve the flow arising from an arbitrary set of unsteady singularities; (*ii*) generation of a large coupled set of differential equations for matching boundary conditions, corresponding to specific discretized geometries (assembled from cylinders and spheres); and (*iii*) calculation of diffusion of conserved scalars (e.g. nutrients, exudates) into and out of these geometries given simple uptake kinetics. Each of these efforts will require approximately 1 mo of P.I. time and 3-5 mo of graduate student time. Riley (1 mo) will review numerical methods and provide technical coordination with the student to insure that the low-Re model is compatible with and can be embedded into the direct numerical simulations of turbulent flows. We request a Pentium-based linux workstation of moderate capabilities ($2500) for code development and to remotely run simulations on other machines available to the PIs. We request software ($1000), and supplies (computer storage and imaging media, etc., $500) for this machine. Riley and Grünbaum will provide additional computer support as needed; however, the student will require full-time use of this machine to conduct and coordinate the modeling component of this grant. We request $300 in Year 1 to cover long-distance charges, photocopying, and other communications.

Year 2

Grünbaum (3 mo) and the graduate student (12 mo) will implement flow calculations for complex, rigid geometries of extant and hypothetical/extinct forms. The developments in Year 2 will include: (*i*) developing algorithms to translate images of real cell geometries (e.g. from digitized SEMs) to discretized geometrical models compatible with the flow simulations and diffusion calculations from Year 1; (*ii*) embedding the flow simulation in Riley's turbulence models; and (*iii*) analysis of results and manuscript preparation. Each of these will require approximately 1 mo of P.I. time and 3-5 mo of graduate student time. Riley (1 mo) and the graduate student will embed the low-Re model into Riley's direct numerical simulations and investigate functional morphology of rigid bodies. This time allotment also includes participation of both Grünbaum and the student in the curriculum development working group at U. Maine. We request travel funds to attend this session for one PI, the graduate student ($2000) and a Washington State teacher ($1000 participant support costs). A teacher stipend is provided in the U. Maine budget. We also request travel for one PI and the graduate student to a domestic national meeting ($1000). We request $1000 to cover publication costs. We request $300 in Year 2 to cover long-distance charges, photocopying, and other communications, and $500 to cover supplies (computer storage and imaging media, etc.).

Year 3

Grünbaum (3 mo) and the graduate student (12 mo) will implement low-Re calculations around flexible phytoplankton cell geometries and motile phytoplankters (dinoflagellates). The developments in Year 3 will include: (*i*) modification of the fluid flow simulator to allow unsteady geometries and feedback between fluid forces and structural flexion; (*ii*) simulation of diffusion of conserved scalars with complex uptake kinetics (e.g. Michaelis-Menten, facilitated diffusion); and (*iii*) analysis of results and manuscript preparation. Each of these will require approximately 1 mo of PI time and 3-5 mo of graduate student time. This time allotment also includes participation of both in the Friday Harbor Laboratories and U. Maine teacher workshops. Riley (1 mo) and the graduate student will embed the flexible cell, low-Re model in the direct numerical simulations of turbulent flows. We request the following participant support for the FHL workshop for Washington State teachers: (7 teachers, 10 d): $3200 room and board, $1050 tuition (3 UW extension credits), $7000 stipend, $1000 travel. We request travel for PI, graduate student ($2000) and Washington State teacher ($1000 participant support costs) to the U. Maine teacher workshop. We request $600 for room and board for a PI and the graduate student for the FHL teachers workshop. We also request travel for one PI and the graduate student to a domestic national meeting ($1000), and $1000 to cover publication costs. We request $300 in Year 3 to cover long-distance charges, photocopying, and other communications, and $500 to cover supplies (computer storage and imaging media, etc.).

Grünbaum and Riley will jointly supervise the graduate student in Years 1, 2 and 3. The request for graduate student support (line G.6.) includes a graduate operating fee which is an integral part of the graduate student support at the University of Washington (Year 1: $7473; Year 2: $7735; Year 3: $8005).

The University of Washington anticipates salaries to increase at 4% per year. Benefit rates are calculated as follows: 21.3% for faculty, 10.7% for graduate students. The current indirect cost rate is 51.6% MTDC as negotiated with DHHS (agreement dated 11/26/01).

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
Purdue University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Steve T Wereley

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Steve T Wereley - Principal Investigator	0.00	0.00	1.50	$ 11,017	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	1.50	11,017	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				18,240	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				29,257	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				4,537	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				33,794	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				3,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				12,600	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				4,092	
TOTAL OTHER DIRECT COSTS				16,692	
H. TOTAL DIRECT COSTS (A THROUGH G)				53,486	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTD (Rate: 50.0000, Base: 53486)					
TOTAL INDIRECT COSTS (F&A)				26,743	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				80,229	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 80,229	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME	FOR NSF USE ONLY		
Steve T Wereley	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Diane troyer			

1 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
Purdue University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Steve T Wereley

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Steve T Wereley - Principal Investigator	0.00	0.00	1.00	$ 7,712	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	1.00	7,712	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				18,960	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				26,672	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				3,453	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				30,125	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				2,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				5,600	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				4,296	
TOTAL OTHER DIRECT COSTS				9,896	
H. TOTAL DIRECT COSTS (A THROUGH G)				42,021	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTD (Rate: 50.0000, Base: 42020)					
TOTAL INDIRECT COSTS (F&A)				21,010	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				63,031	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 63,031	$

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Steve T Wereley

ORG. REP. NAME*
Diane troyer

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

0221003

SUMMARY PROPOSAL BUDGET   YEAR 3

ORGANIZATION **Purdue University**	**FOR NSF USE ONLY** PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Steve T Wereley**	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Steve T Wereley - Principal Investigator	0.00	0.00	1.00	$ 8,097	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	1.00	8,097	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				19,690	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				27,787	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				3,659	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				31,446	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				4,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				3,200	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				4,512	
TOTAL OTHER DIRECT COSTS				7,712	
H. TOTAL DIRECT COSTS (A THROUGH G)				43,158	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTD (Rate: 50.0000, Base: 43158)					
TOTAL INDIRECT COSTS (F&A)				21,579	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				64,737	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 64,737	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME **Steve T Wereley**	**FOR NSF USE ONLY** INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Diane troyer**	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

0221003

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION: **Purdue University**				FOR NSF USE ONLY	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: **Steve T Wereley**				PROPOSAL NO. / AWARD NO.	DURATION (months): Proposed / Granted

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Steve T Wereley - Principal Investigator**	0.00	0.00	3.50	$ 26,826	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	3.50	26,826	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (3) GRADUATE STUDENTS				56,890	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				83,716	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				11,649	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				95,365	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				9,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				21,400	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				12,900	
TOTAL OTHER DIRECT COSTS				34,300	
H. TOTAL DIRECT COSTS (A THROUGH G)				138,665	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				69,332	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				207,997	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 207,997	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME	FOR NSF USE ONLY		
Steve T Wereley	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG
Diane troyer			

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

F. Budget Justification
Purdue University

SENIOR PERSONNEL

The PIV components will be purchased and assembled under the direction of Steve Wereley (Purdue), who has eight years experience in building specialized PIV systems that achieve greater spatial resolution, temporal resolution and accuracy than comparably priced commercial systems. Several of these are described on web pages at <http://widget.ecn.purdue.edu/~swereley/piv.html> and <http://widget.ecn.purdue.edu/~swereley/nozzle.html>. He will also provide his custom-written PIV software to the project free of charge and optimize it for the Couette experiments to be performed. Wereley has budgeted time at the Darling Marine Center in 2002 to complete the assembly, debug the system, and train the end users. During year 1, Wereley will hire a masters student to begin designing and constructing the first two Couette devices. Wereley and the masters student will also design and purchase the necessary PIV components. During the summer of the first year, Wereley will travel to Darling Marine Center to assemble and test the PIV system as well as to deliver the completed Couette devices. During year 2, Wereley and the masters student will interact with the other investigators and fine tune both the PIV system as well as the Couette devices. During year 3 Wereley and the masters student will assist the other investigators in interpreting the results of the experiments and with any redesign of the experimental equipment.

CAPITAL EQUIPMENT

No capital equipment will have to be purchased at Purdue. The researchers at Purdue will use the PIV system that Steve Wereley and his graduate students built over the course of the last several years using departmental, state, and industrial funds.

TRAVEL

Domestic travel funds are allocated for traveling among the various labs involved in the proposed research as well as to attend national conferences for dissemination of results. In year 1, Steve Wereley will travel to Darling Marine Center twice. During the first year, we will have a planning meeting of senior participants in late spring at the Darling Center, after we have exchanged detailed plans and protocols. The second trip will be one month in duration to assemble and test the PIV system, deliver the Couette devices, and train the PIV users in its operation. In years 2 and 3, Wereley will travel to national meetings. In year 3, the masters student working at Purdue will participate in the Friday Harbor course as well as travel to Darling Marine Center.

OTHER INDIRECT COSTS

Materials and Supplies: Rather large expenditures are planned for M&S at Purdue to cover the cost of fabricating the three Couette devices. The first two identical devices will be made during the first year at a budgeted cost of $4200 each. The largest cost associated with fabricating these Couette devices will be the two DC servo motors necessary to rotate the inner and outer cylinders in opposite directions at arbitrary rates. The two concentric cylinders will be housed inside a rectangular box filled with liquid of the same refractive index as that in the gap between the two cylinders, minimizing the optical distortion caused by the curved outer cylinder. The third Couette device will be built during the second year and, while physically larger, will be easier to build and will cost $2500. This device will have a stepper motor driving only the inner cylinder that can be detached so that the inner cylinder can also be driven with a handle for demonstration purposes. Each year $2500 is budgeted for purchasing fluorescent tracer particles in the 1 micron range for measurements quantifying the steady and unsteady shear rates inside the Couette devices. Since there will not be any phytoplankton in these experiments, it is anticipated that the particles and the fluid can be reused significantly longer than in the experiments at Darling Marine Center. Each year shipping costs are also budgeted to cover the cost of shipping the three large Couette devices between Purdue and Darling Marine Center, both for initial delivery as well as for any adjustments that may need to be made after their initial construction.

Other: This category (line G.6 on Purdue budget pages) contains only the fee remits that cover graduate student tuition and fees, which are not included elsewhere in the budget.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Peter A. Jumars

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title: Food substrates and digestive capabilities of marine deposit feeders

Note: No-cost extension to end of Sept. 2002 has been obtained due to slowing of progress by P. Jumars' move to Maine

Source of Support: NSF Biological Oceanography OCE-9617701

Total Award Amount: $ 315,761 Total Award Period Covered: 04/01/97 - 09/30/02

Location of Project: University of Washington

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1 (1997 - 1999)

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title: The Shallow Scattering Layer: Emergence Behaviors of Coastal Macrofauna

Source of Support: ONR (DEPSCoR), N00014-00-1-0662

Total Award Amount: $ 430,823 Total Award Period Covered: 05/01/2000 - 04/30/03

Location of Project: University of Maine

Person-Months Per Year Committed to the Project. Cal: 2 Acad: Sumr: 2

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title: Effects of Benthic Biota on Backscatter: Experiments with the Portable Acoustic Laboratory (PAL)

Source of Support: ONR, N00014-00-1-0035

Total Award Amount: $ 29,668 Total Award Period Covered: 10/1/01 - 9/30/02

Location of Project: University of Maine

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 0.5

Support: [X] Current [ ] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title: Effects of Benthic Biota on Acoustic Propagation: Completion of SAX 99 Analysis

Source of Support: ONR, N00014-02-1-0091

Total Award Amount: $ 32,521 Total Award Period Covered: 10/1/01 - 9/30/02

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 0.5

Support: [ ] Current [X] Pending [ ] Submission Planned in Near Future [ ] *Transfer of Support

Project/Proposal Title: Collaborative Proposal: Form and function of phytoplankton in unsteady, low Reynolds-number flows

Source of Support: NSF (Biological Oceanography)

Total Award Amount: $ 405,072 Total Award Period Covered: 09/01/02 - 08/31/05

Location of Project: University of Maine

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1 or 2

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Peter A. Jumars

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☐ Pending ☒ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Biocomplexity: Autocatalysis of organic matter preservation (L. M. Mayer, PI)

Source of Support: NSF (Biocomplexity)

Total Award Amount: $ $2M (approx.) Total Award Period Covered: 01/01/02 - 12/31/06

Location of Project: University of Maine

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Nutritional control of bioturbation in marine sediments (L. M. Mayer, PI)

Source of Support: ONR (DEPSCoR)

Total Award Amount: $ 712,937 Total Award Period Covered: 10/01/02 - 9/30/05

Location of Project: University of Maine

Person-Months Per Year Committed to the Project. Cal: 1 Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Other agencies (including NSF) to which this proposal has been/will be submitted.

Investigator: Lee Karp-Boss

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Scattering characteristics of phytoplankton taxonomic groups and their effects on reflectance

Source of Support: NASA

Total Award Amount: $ 125,109 Total Award Period Covered: 04/01/02 - 03/31/05

Location of Project: University of Maine

Person-Months Per Year Committed to the Project. Cal: 4.2 Acad: Sumr:

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Collaborative Proposal: Form and function in unsteady, low Reynolds-number flows

Source of Support: NSF (OCE-Biological Oceanography)

Total Award Amount: $ 405,072 Total Award Period Covered: 09/01/02 - 08/31/05

Location of Project: University of Maine

Person-Months Per Year Committed to the Project. Cal: 6 Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Kevin J. Eckelbarger

Other agencies (including NSF) to which this proposal has been/will be submit-

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Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Ira C. Darling Marine Center REU Proposal

Source of Support: NSF (REU)

Total Award Amount: $ 172,000 Total Award Period Covered: 1 May 2002 - 30 April 2006

Location of Project: University of Maine

Person-Months Per Year Committed to the Project. Cal: 0.2 Acad: Sumr: (no PI time)

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Collaborative Proposal: Form and function in unsteady, low Reynolds-number flows

Source of Support: NSF (OCE-Biological Oceanography)

Total Award Amount: $ 322,715 Total Award Period Covered: 1 January 2002 - 31 December 2004

Location of Project: Darling Marine Center, University of Maine

Person-Months Per Year Committed to the Project. Cal: 0.5 Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Renovation and Expansion of the Darling Center Library

Source of Support: NSF - Field Stations & Marine Labs Program

Total Award Amount: $ 140,000 Total Award Period Covered: 1 September 2001 - 31 August 2003

Location of Project: University of Maine

Person-Months Per Year Committed to the Project. Cal: 0.2 Acad: Sumr: (no PI time)

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Collaborative Proposal: Form and function in unsteady, low Reynolds-number flows

Source of Support: NSF (Biological Oceanography)

Total Award Amount: $ 405,072 Total Award Period Covered: 1 September 2002 - 31 August 2005

Location of Project: Darling Marine Center, University of Maine

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (10/99) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Thomas Kiørboe

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Collaborative Proposal: Form and function in unsteady, low Reynolds-number flows

Source of Support: NSF (Biological Oceanography)

Total Award Amount: $ 405,072 Total Award Period Covered: 09/01/02 - 08/31/05

Location of Project: Darling Marine Center, University of Maine

Person-Months Per Year Committed to the Project. Cal: 0.2 Acad: Sumr:

Please Note: Other funding to Thomas Kiørboe is not listed, as the Danish funding system is not strictly comparable to the U.S. This form is included because the Fastlane program that checks for completeness of proposals expects to find it for each senior investigator.

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Timothy J. Pedley

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Collaborative Proposal: Form and function in unsteady, low Reynolds-number flows

Source of Support: NSF (Biological Oceanography)

Total Award Amount: $ 405,072 Total Award Period Covered: 09/01/02 - 08/31/05

Location of Project: Darling Marine Center, University of Maine

Person-Months Per Year Committed to the Project. Cal: 0.2 Acad: Sumr:

Please Note: Other funding to Timothy J. Pedley is not listed, as the English funding system is not strictly comparable to the U.S. This form is included because the Fastlane program that checks for completeness of proposals expects to find it for each senior investigator.

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: André W. Visser

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Collaborative Proposal: Form and function in unsteady, low Reynolds-number flows

Source of Support: NSF (Biological Oceanography)

Total Award Amount: $ 405,072 Total Award Period Covered: 09/01/02 - 08/31/05

Location of Project: Darling Marine Center, University of Maine

Person-Months Per Year Committed to the Project. Cal: 0.2 Acad: Sumr:

Please Note: Other funding to André W. Visser is not listed, as the Danish funding system is not strictly comparable to the U.S. This form is included because the Fastlane program that checks for completeness of proposals expects to find it for each senior investigator.

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support
(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Daniel Grunbaum

Other agencies (including NSF) to which this proposal has been/will be submitted. None

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ * Transfer of Support
Project/Proposal Title:
Collaborative Research: Form and Function of Phytoplankton in Unsteady, Low Reynolds-Number Flows (this proposal)

Source of Support: NSF
Total Award Amount: $ 356,512 Total Award Period Covered: 09/01/02 – 08/31/05
Location of Project: University of Washington
Person-Months Per Year Committed to the Project. Cal.: 3.0 Acad: Sumr:

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ * Transfer of Support
Project/Proposal Title: Coordinated Motion of Natural and Man-Made groups

Source of Support: NSF
Total Award Amount: $ 855,000 Total Award Period Covered: 1/00-12/02
Location of Project: University of Washington
Person-Months Per Year Committed to the Project. Cal.: 3.0 Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ * Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal.: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ * Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal.: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ * Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal.: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support for James J. Riley
January 2002

NSF Grant No.: CTS-9810103
Period: 10/1/98 to 9/30/02
Amount: $350,664
person-months: 1
Title: Modeling Nonpremixed Turbulent Combustion

ONR Grant No.: N00014-00-1-0752
Period: 7/1/00 to 6/30/02
Amount: $146,279
person-months: 1
Title: Dynamics of Turbulence Strongly Influenced by Buoyancy

NASA Grant No.: NAG 3-2517
Period: 12/13/00 to 11/30/04
Amount: $380,000
person-months: 1/2
Title: Investigation of Lift-off and Blow-out of Transitioning and Turbulent Flames

NSF Grant Proposal
Period: 01/01/02 to 12/31/05 (requested)
Amount: $399,669
person-months: 1
Title: Computational Simulation of Complex Turbulent Diffusion Flames

NSF Grant (proposal in development -- this proposal)
Period: 09/01/02 to 08/31/05
Amount: $356,512
Person-months: 1
Title: Form and Function of Phytoplankton in Unsteady, Low Reynolds-Number Flows

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Steve Wereley**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Intelligent MEMS-based Flow Sensors and Controllers**

Source of Support: **21st Century Research and Technology Fund**

Total Award Amount: $ **815,630** Total Award Period Covered: **08/01/00 - 07/31/02**

Location of Project: **Purdue University, West Lafayette, IN**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **1.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Integrated Detection of Hazardous Materials**

Source of Support: **Naval Surface Warfare Center, Crane Division**

Total Award Amount: $ **7,000** Total Award Period Covered: **06/01/01 - 06/01/03**

Location of Project: **Purdue University, West Lafayette, IN**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **1.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Center For Nanoscale Electronics/Biological Devices**

Source of Support: **21st Century Research and Technology Fund**

Total Award Amount: $ **1,480,000** Total Award Period Covered: **08/01/00 - 07/31/02**

Location of Project: **Purdue University, West Lafayette, IN**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **3M Nontenured Faculty Grant**

Source of Support: **3M**

Total Award Amount: $ **36,000** Total Award Period Covered: **03/22/00 - 03/21/03**

Location of Project: **Purdue University, West Lafayette, IN**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **0.00**

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Towards Prevention and Control of Arteriosclerosis: Endothelial and Smooth Muscle Cell Response to Pulsatile Flow in Stenotic Vessels**

Source of Support: **Showalter Trust Fund**

Total Award Amount: $ **83,000** Total Award Period Covered: **08/01/01 - 07/31/02**

Location of Project: **Purdue University, West Lafayette, IN**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Summ: **0.00**

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Steve Wereley**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Explorations in Biomedical Microdevices: Brownian Motion and Education**

Source of Support: **National Science Foundation**

Total Award Amount: $ **100,000** Total Award Period Covered: **04/01/02 - 03/31/03**

Location of Project: **Purdue University, West Lafayette, IN**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.00** Sumr: **1.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: **Flow in Stenotic Vessels: Fluid Stimuli and Cellular Response**

Source of Support: **National Institute of Health**

Total Award Amount: $ **2,467,500** Total Award Period Covered: **09/01/02 - 08/31/05**

Location of Project: **Purdue University, West Lafayette, IN**

Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.50** Sumr: **1.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory: **Jumars has a Zeiss epifluorescence microscope and low-light CCD camera that will be useful for visualizing phytoplankton and helping to interpret images recorded on the proposed PIV sysem (i.e., in looking at phytoplankton autofluorescence). Its slow response time and high light sensitivity make it unsuitable for PIV.**

Clinical:

Animal:

Computer: **Jumars has several Macintosh power computers, one DEC Alpha (au) workstation and a PC (486) associated with an image analyzer for the Zeiss. Karp-Boss is purchasing an additional PC as part of her startup package.**

Office:

Other: **The Darling Marine Center has completed construction of a new cold-water aquaculture facility, including several temperature- and light-controlled rooms that will provide ideal culture facilities for this work, courtesy of Mary Jane Perry.**

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

The Darling Marine Center houses a Zeiss 10A Transmission Electron Microscope and a Zeiss 940A Scanning Electron Microscope.

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory: **If needed, laboratory facilities includig running seawater, microscopes, video equipment, and motion-tracking soft- and hardware are available in Grunbaum's labs at UW's main campus and/or Friday Harbor Laboratories.**

Clinical: **None.**

Animal: **None.**

Computer: **In addition to the workstation we request, the PIs have several linux and SGI CPUs available for remote batch processing of large-scale computations (as opposed to code development). In particular, the principal investigators are part of a small group of researchers that has established a 18-node Beowolf cluster of 500~MHz Pentium III**

Office: **Both PIs and the graduate student are provided with offices at UW with telephone and ethernet.**

Other: **None.**

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

No major equipment will be required other than that already available in the PIs labs or requested in the grant.

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

Support staffs are available in Oceanography and Mechanical Engineering consisting of secretarial and network support. These human resources will be sufficient for activities related to this grant.

COMPUTER FACILITIES (continued):

processors. The cluster has 2GB distributed memory, 32GB distributed disk storage, all connected by a 100baseT switch. This cluster is being used to develop experience with parallel computer architecture, to develop and debug programs using Message Passing Interface (MPI) parallelization protocol, and for moderate-size simulations. All needed peripherals such as printers and backup tape drives are available in the labs of the PIs.

H. Facilities
Purdue University

Velocity Characterization
Professor Wereley has been building his microfluidics laboratory at Purdue University during the last several years using departmental start up funds, voluntary support, and government grants. It is equipped with a high-speed, high-resolution interline transfer CCD camera (Lavision Flowmaster 3S), several microscopes (inverted epi-fluorescent Nikon TE200 microscope, Leica Leitz metallurgical microscope), and a Nd:YAG laser, allowing various state of the art microfluidic diagnostic techniques to be performed. The laboratory also contains the necessary support equipment for microfluidics research such as syringe pumps, a laminar flow hood, data acquisition systems, oscilloscopes, delay generators, etc. Three particle image velocimetry (PIV) packages are available, 2 custom-written and 1 from Lavision, Inc.

Machine Shop Facilities
The Couette devices described in this proposal will be built in the student machine shop in the Mechanical Engineering Department at Purdue University by the masters student involved in the proposed research. The student shop contains the standard mills and lathes along with several CNC mills and lathes which the student will learn to operate in order to build the three Couette devices to very tight tolerances.

MMSTEC Maine's Mathematics & Science Teaching
Excellence Collaborative

Project Address:
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Principal Investigators:
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University of Southern Maine

Francis Eberle
Maine Mathematics and Science Alliance

Robert Franzosa
University of Maine

Mary Ann McGarry
University of Maine

Mary Schwanke
University of Maine at Farmington

Herman Weller
University of Maine

Collaborative Partners:
Maine Mathematics and Science Alliance
University of Southern Maine
University of Maine
University of Maine at Farmington

March 20, 2001

To Reviewers of This Grant:

I am Richard Stebbins, Professor of Chemistry at University of Southern Maine, and PI for an NSF Systemic CETP project (proposal number 9987444) named MMSTEC. The project involves three campuses of the University of Maine System, the University of Maine, Orono, the University of Maine, Farmington, the University of Southern Maine, and the Maine Mathematics and Science Alliance. The goals of the five-year project, currently in its first year, are to increase the number of qualified 6-12 mathematics and science teachers in Maine, and to improve the quality of mathematics/science instruction in teacher education programs in the University of Maine System campuses.

Recently, I have had discussions with Peter Jumars of the Darling Marine Center about the educational aspects of the proposal before you. Peter proposes to create two, month summer internships of a month or two months duration for in-service teachers. These internships would be during the summers of the last two grant years, and would involve the teachers in developing materials and teaching strategies associated with some of the research findings of the Darling Center.

This is a wonderful way to both expose teachers to a research environment with local significance, and to bring some of the findings of the Center to the school children of Maine. Our role, would be a connect the Center to qualified teachers at the appropriate educational level. I heartily support this aspect of the proposal, and congratulate the Darling Center for combining its scholarship with the continuing education of Maine children.

Sincerely,

Richard Stebbins

Richard Stebbins, Project Director,
MMSTEC

Ministeriet for Fødevarer, Landbrug og Fiskeri
Danmarks Fiskeriundersøgelser

Dr. Peter A. Jumars
Darling Marine Center
University of Maine
193 Clark's Cove Road
Walpole, ME 04573-3307

March 29, 2001

Re: Form, function and interaction in unsteady, low-*Re* flows

Dear Pete,

This is to confirm that Andy Visser and I agree to participate in the project on unsteady, low *Re*-flows, if funded. We plan to pursue work on zooplankton sensory biology as described in the proposal.

We hope also to be able to host you, your co-workers and students on visits in our laboratory. Likewise we look forward to visit our US counterparts in Maine or Friday Harbor for exchange of ideas and to conduct collaborative work.

We see this as a unique opportunity to promote much needed transatlantic co-operation within our field.

We wish you good luck with the proposal.

Best wishes

Thomas Kiørboe
Professor

X-Sieve: cmu-sieve 2.0
Date: Sun, 12 Aug 2001 06:47:37 -0700
Subject: Re: Teachers
From: "M. Patricia Morse" <mpmorse@u.washington.edu>
To: Pete Jumars <jumars@maine.edu>, <grunbaum@ocean.washington.edu>

Dear Pete and Danny,

This sounds just fine. Lets do it, and we will find that partner teacher for you out here. I have been preparing for a keynote at the Vienna meetings and at the same time helping the Illg family with Ruth in her last month or so with terminal cancer. It is easier than it sounds, as her attitude about the last phase of her life is so upbeat - it keep us up there too.

So I will plan to be the science partner here for the teacher - and during that summer, I will work with him or her to devise the works for the next year. Sounds good to me. I suspect I too should be learning!!!
You might add the partnership idea, with some added input on inquiry on this end from perhaps two visitors who are science educators here at UW that summer - on inquiry - we can then say it is a true partnership between scientist, science educator and teacher in the implementation of both courses. I add my short bio. Let me know if you need anything else.
I have not let this down, so we will make it work, thanks for you patience,

best trish

M. Patricia Morse, Ph.D
Professor of Zoology, (Acting)
Department of Zoology
Box 351800; 24 Kincaid
University of Washington
Seattle, WA 98195

Short Biographical Sketch for M. Patricia Morse

M. Patricia Morse is a marine biologist and science educator at the University of Washington. For thirty-four years, she was Professor of Biology at Northeastern University. The last four of those years were spent as a Program Director at the National Science Foundation (NSF) in the Division of Elementary, Secondary and Informal Education as a specialist in biology and environmental science in Instructional Materials Development. Dr. Morse holds a BS degree from Bates College, an MS and Ph.D. from the University of New Hampshire, and an honorary D.Sc. from Plymouth State College. Dr. Morse has published over 50 papers and 34 abstracts in molluscan biology and more recently in science education. Her work in functional morphology involves microscopic analysis (transmission and scanning electron and confocal microscopy) of the bivalve heart-kidney system as well as molluscan meiofaunal ecology and systematics studies. She currently serves as Principal Investigator for the Independent College Office on an NSF K-12 Partnership project and chairs a National Academies of Sciences NRC Committee on Attracting Science and Mathematics Ph.Ds to K-12 Education."She also serves on the Advisory group for the UW Sustaining Seattle Teachers Initiative. Dr. Morse is a past president of Sigma Xi, the Scientific Research Society and the American Society of Zoologists (now the Society for Integrative and Comparative Biology) and is a Fellow of the AAAS (American Association for the Advancement of Science). She is a member of the Board of Trustees at Bates College, serves on the editorial boards of *Acta Zoologica* and *American Zoologist*, is vice-chair of the International Union of Biological Sciences' Commission for Biological Education and chairs the Education Committee of the American Institute of Biological Sciences. She is an Acting Professor on the Faculty of the Zoology Department at the University of Washington.

Morse, M. P. 1994. Current knowledge of reproductive biology in two taxa of interstitial molluscs (class Gastropoda: order Acochlidiacea and class Aplacophora: order Neomeniomorpha). In: *Reproduction and Development of Marine Invertebrates*. Wilson, W. H., Stricker, S. A. and G. L. Shinn (Eds). Johns Hopkins University Press, Baltimore, MD.

Morse, M. P. and P.D. Reynolds. 1996. Ultrastructure of the heart-kidney complex in smaller classes supports symplesiomorphy of molluscan coelomic characters. In: *Origin and evolutionary Radiation of the Mollusca*. Taylor, J. D. (Ed.) Malacological Society of London, Oxford University Press, London.

Meyhöfer E. and M. P. Morse. 1996. Characterization of the bivalve ultrafiltration system in *Mytilus edulis, Chlamys hastata,* and *Mercenaria mercenaria*. Invert. Biol. **115**: 20-29..

Morse, M. P. and J. D. Zardus. 1997. Bivalvia. In: *Microscopic Anatomy of Invertebrates*. Vol **6A:** *Mollusca II*. F. W. Harrison and A. J. Kohn (Eds.). Chapter 2, pp 7 - 118. Wiley Liss Inc., New York, NY.

Morse, M. P. and the Review Team. 2001. *A Review of Biological Instructional Materials for Secondary Schools*. Funded by the David and Lucile Packard Foundation. American Institute of Biological Sciences, Washington, DC.

UNIVERSITY OF WASHINGTON
SEATTLE WASHINGTON 98195-1800

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August 14, 2001

Dr. Peter Jumars
Darling Marine Center
193 Clark's Cove Road
Walpole, ME 04573

Dear Dr. Jumars

I would like to add my enthusiastic support for the proposed effort by Drs. Grünbaum, Jumars, Karp-Boss, Riley and Wereley to study the interactions of phytoplankton with unsteady flows. I have had an interest in unsteady flows and fluid-solid interactions for some time (e.g., Daniel 1984), and am eager to see this new approach to unsteady flow problems at low Reynolds numbers. I maintain a laboratory with a variety instruments for measuring kinematics and dynamics of stress and strain in single cells and plan to make them available to this study. These instruments include micro and nanoscale force measurement, fully equipped muscle-lever systems with force and length feedback, three digital highspeed video cameras, expertise in microimaging and computational image tracking, and a host of optical and silicon-based strain and force sensors. I will be pleased to make these available to you and your collaborators. Indeed I have always maintained a great working relationship with you and Drs. Grunbaum and Karp-Boss and Riley. I have no hesitation in fostering ever stronger links. Please let me know if there are more specific needs you will have.

Sincerely

Thomas Daniel

Daniel, T.L. 1984. Unsteady aspects of aquatic locomotion. Am. Zool. 24: 121-134.

UNIVERSITY OF CAMBRIDGE
Department of Applied Mathematics and Theoretical Physics
Silver Street, Cambridge, England CB3 9EW

From: Professor T.J. Pedley FRS
G.I. Taylor Professor of Fluid Mechanics
Head of Department
Tel: +44-(0)1223-339842
Fax: +44-(0)1223-312984
E-mail: tjp3@damtp.cam.ac.uk

7 February, 2002

Peter A. Jumars
University of Maine
Darling Marine Center
193 Clark's Cove Road
Walpole, ME 04573-3307
U.S.A.

Dear Pete

This short note is to confirm that I have given you feedback on the text of your proposal to the U.S. National Science Foundation entitled "Collaborative Proposal: Form and function of phytoplankton in unsteady, low Reynolds-number flows". The project is a very interesting one and I would enjoy participating in the research. I would be pleased to give your group of collaborators help in planning specific modelling approaches, interpreting model outputs and comparing them with experimental results.

Yours sincerely

Tim Pedley

Professor T J Pedley

Note to reviewers: The text of the letter, which is scanned from a fax, is reproduced here to ease the task of reading it:
"This short note is to confirm that I have given you feedback on the text of your proposal to the U.S. National Science Foundation entitled "Collaborative Proposal: Form and function of phytoplankton in unsteady, low Reynolds-number flows". The project is a very interesting one and I would enjoy participating in the research. I would be pleased to give your group of collaborators help in planning specific modelling approaches, interpreting model outputs and comparing them with experimental results."