Research Grant - New York Univ.

To cover costs on continuation of unsolicited proposal "Numerical Design of Transonic Shockless Airfoils" by New York University, under a research grant.

The proposed analysis will greatly aid in the design of transonic wings. This proposal will also supplement the experimental research on this problem being carried out in the Langley 8-foot transonic pressure tunnel.

(This job order will supersede REH-619)
TO: Dr. Richard T. Whitcomb, M/S 359  
FROM: Technical Assistant for Group 3  
DATE: August 17, 1970  
SUBJECT: Proposed work for Langley by Garabedian on transonic shockless airfoils

As we discussed, I told Mr. Garrick you are delighted to have him as co-monitor on the subject work and that you will keep him informed of its progress. I sent Mr. Garrick a copy of the proposal and correspondence relating to it. The proposal at this time is still in the Budget Office. It is being held up pending RTOP approval by Headquarters. The RTOP negotiation will probably take several weeks.

Robert W. Boswinkle, Jr.  
3486, M/S 117

cc:  
Mr. I. E. Garrick, M/S 242
Proposal: Numerical Design of Transonic Shockless Airfoils

For many reasons, including limitations on the feasibility of the SST, it has become desirable to make the performance of commercial and military subsonic aircraft faster and more efficient. Operation at higher speeds becomes impaired at the force-break Mach number of an airfoil by an unacceptable increase in wave drag. It is, therefore, important to develop airfoil shapes that will admit shock-free transonic flow at design conditions, thus resulting in a higher force-break Mach number. The experimental work of Pearcey and Spee has demonstrated that such flows can be realized in the laboratory, and Whitcomb's discovery of the supercritical upside-down wing has shown how to exploit them in practice.

Motivated by these considerations, we have started to develop a program for the numerical construction of shockless transonic airfoils at the A.E.C. Computing and Applied Mathematics Center of the Courant Institute at N.Y.U. An inverse method originally used to solve the detached shock problem [1-3] has been modified to calculate two-dimensional steady inviscid flows past profiles with closed supersonic zones free of shocks. The procedure uses analytic continuation into a complex extension of the hodograph plane, where a stable finite difference scheme based on complex characteristics is used. Physically reasonable flows with a moderate adverse pressure gradient that can be presumed not to induce separation of the turbulent boundary layer are obtained with apparently much more rapidity and flexibility than is encountered with the other hodographs methods available, such as Nieuwland's [7]. A detailed A.E.C. report by Korn [5], including a print-out of his Fortran program, has been published for the case of symmetric airfoils without lift.

The A.E.C. cannot be expected to support a more extensive project to develop our airfoil computations into a tool available to engineers for everyday application. We have made feasibility studies that show we can now produce lifting shockless airfoils in less than one minute of C.D.C. 6600 computing time. However, before this was accomplished, it became necessary to make extensive parameter studies in order to achieve a closed profile, together with a moderate pressure distribution such that the boundary layer should not separate. In this proposal, we request that N.A.S.A. undertake to finance a continuation of our research so that our preliminary success can lead to a technique that any engineer unfamiliar with the mathematical subtleties can have at his disposal as a workable and inexpensive computing program for transonic airfoil design.
In addition to making lifting shockless transonic airfoil shapes easy to calculate, we propose to generalize our procedure so that a turbulent boundary layer correction can be made. More specifically, we have in mind a model including a boundary layer wake permitting the drag coefficient at a given Reynolds number to be predicted along with the associated displacement thickness. Moreover, we want ultimately to prepare numerical schemes to calculate the flow past our shockless airfoils at off-design conditions so as to predict their aerodynamic characteristics mathematically.

All this will require the services of several senior scientists and computer programmers, in addition to the principal investigator.

Together with our program of mathematical research and development we would like to cooperate with N.A.S.A. in testing the performance of our lifting shockless airfoils in a wind tunnel. Because of the importance of suppressing boundary layer separation, if shock-free flow is truly to prevail, it becomes necessary to operate at such high Reynolds numbers that the boundary layer will become primarily turbulent. We hope, therefore, that tests on our airfoils can be conducted in a high speed wind tunnel.

In addition to the practical matter of systematizing and documenting our numerical scheme so that it can become a standard tool available to engineers for design purposes, we intend to investigate the physical properties and stability of smooth transonic flows. Early theoretical results [6] and [4] have shown that a smooth, steady transonic flow, if disturbed, will give rise to a shock. However, these shocks are weak and the disturbed flow with weak shock could be described by appropriate singular solutions of the hodograph equations, but cannot be solved in quite the explicit manner described in Guderley [4], p. 122. However, in principle, this approach is feasible. In this direction, preliminary results have already been obtained concerning the correctness of the Dirichlet problem for Tricomi's mixed equation [6].

Principle Investigator: Paul R. Garabedian
Professor of Mathematics
References:

1. GARABEDIAN, PAUL R.
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   "Transonic potential flow around a family of quasi-elliptical aerofoil sections",

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Numerical Design of Transonic Shockless Airfoils

**Proposed Budget**

September 1, 1970 to August 31, 1971

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Note: Salaries are based on Estimated 1970-71 Figures.
Curriculum Vitae

Paul R. Garabedian

Born: August 2, 1927, Cincinnati, Ohio

Education:
- AB 1948 Brown
- AM 1947 Harvard
- Ph. D. 1948 Harvard

Positions:
- National Research Council Fellow 1948-49
- Assistant Professor-Math, University of California 1949-50
- Assistant Professor-Math, Stanford, 1950-52
- Associate Professor-Math, Stanford, 1952-56
- Professor-Math, Stanford, 1956-59
- Professor-Math, Courant Institute of Mathematical Sciences, New York University, 1959 - present.

Honors:
- American Academy of Arts & Sciences
- Sloan Foundation Fellowship, 1961-63
- Guggenheim Fellowship, 1966.

Professional Societies
Memberships:
- American Math Society
- Society for Industrial and Applied Math
- National Research Council - Math Division

Recent Publications:


Recent Publications:


Curriculum Vitae

Cathleen Synge Morawetz

Born: May 5, 1923, Toronto, Canada

Education:
University of Toronto, 1940-43 Received B. A.
1944-45

Technical Assistant for Inspection Board
of the United Kingdom and Canada, 1943-44

Massachusetts Institute of Technology, 1945-46 Received M.S.

New York University: Research assistant and student, 1946 - 50, Received Ph. D. in 1951.
Thesis in field of fluid dynamics on stability of an implosion.

Positions:
Research Associate at M.I.T., 1951-52

New York University: Research Associate 1952-57
Assistant Professor 1957-60
Associate Professor 1960-65
Professor 1965 - present

Honors:
Guggenheim Fellow, 1966-67

Professional Societies:
American Math Society

Recent Publications:

........., Energy identities for the wave equation,

........., Exponential decay of solutions of the wave equation.

........., Transonic flow and mixed equations, Rendiconti del Seminario
Matematico dell Universita e del Politecnico di Torino, Vol. 25, pgs.


Curriculum Vitae

Frances Bauer

Born: July 5, 1923, New York City, N. Y.

Education:

A. B. - Brooklyn College, 1943
Ph. D. - in Applied Math, Brown Univ., 1948

Positions:

Research Associate, Brown Univ., 1945-48
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Senior Mathematician, Reeves Instrument Corp., 1950-51, 1952-61
Mathematician, Bureau of Standards, contract with American University, 1951-52
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Membership:

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Rockefeller Foundation Fellowship, 1943-45
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David G. Korn

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Honors:

Graduated Cum Laude

Nominated to PI MU EPSILON Math Honorary

National Science Foundation Fellowship

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SIAM
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June 17, 1970

Mr. Frank P. Smith
Office of University Affairs
Code Y
National Aeronautics and Space Administration
Headquarters
Washington, D.C.

Dear Mr. Smith:

We wish to submit the following research grant proposal on behalf of New York University:

Title: Numerical Design of Transonic Shockless Airfoils

Principal Investigator: P. R. Garabedian

Senior Faculty: C. S. Morawetz

Amount: $135,000

Period: September 1, 1970 to August 31, 1971

We are enclosing a description of the proposal, a detailed budget for one year, recent bibliographies and curriculum vitae for the principal investigator and other participants.

The principal investigator, Professor Garabedian, has discussed the proposal in detail with Dr. Laurence K. Loftin and Dr. Richard T. Whitcomb of Langley Research Center, who have expressed keen interest in the scientific problems concerned. We hope you will bring this submission to their attention.

New York University represents that no company or person, other than a full time member of the staff, has helped solicit or secure this grant. I certify that the distribution of costs between the direct and indirect categories, as shown in the proposal, conforms to the usual accounting practices of the Institution for all Federally supported or sponsored research.
An overhead rate of 54% of salaries has been accepted by the Office of Naval Research for the Department of Defense for the period January 1, 1970 through March 31, 1971.

We would like to express our hope that this program can be initiated and look forward to our cooperation with your agency in this fundamental work.

Sincerely,

Jurgen Moser
Director, CIMS and Head, All-University Dept. of Mathematics

JM: fbb
Enc.

cc: Dr. Richard T. Whitcomb
Dr. Laurence K. Loftin
Proposal: Numerical Design of Transonic Shockless Airfoils

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Proposal: Numerical Design of Transonic Shockless Airfoils

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SIAM
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#### Proposed Budget

**September 1, 1970 to August 31, 1971**

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Recent Publications:


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NASA-Langley (July 1969)  ASD-GP&MS
Mr. Frank P. Smith  
Office of University Affairs  
Code Y  
National Aeronautics and Space Administration  
Headquarters  
Washington, D.C.

Dear Mr. Smith:

We wish to submit the following research grant proposal on behalf of New York University:

**Title:** Numerical Design of Transonic Shockless Airfoils  
**Principal Investigator:** P. R. Garabedian  
**Senior Faculty:** C. S. Morawetz  
**Amount:** $135,000  
**Period:** September 1, 1970 to August 31, 1971

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Sincerely,

Jurgen Moser
Director, CIMS and
Head, All-University
Dept. of Mathematics

cc: Dr. Richard T. Whitcomb
    Dr. Laurence K. Loftin
Proposal: Numerical Design of Transonic Shockless Airfoils

For many reasons, including limitations on the feasibility of the SST, it has become desirable to make the performance of commercial and military subsonic aircraft faster and more efficient. Operation at higher speeds becomes impaired at the force-break Mach number of an airfoil by an unacceptable increase in wave drag. It is, therefore, important to develop airfoil shapes that will admit shock-free transonic flow at design conditions, thus resulting in a higher force-break Mach number. The experimental work of Pearcey and Spee has demonstrated that such flows can be realized in the laboratory, and Whitcomb's discovery of the supercritical upside-down wing has shown how to exploit them in practice.

Motivated by these considerations, we have started to develop a program for the numerical construction of shockless transonic airfoils at the A.E.C. Computing and Applied Mathematics Center of the Courant Institute at N.Y.U.. An inverse method originally used to solve the detached shock problem [1-3] has been modified to calculate two-dimensional steady inviscid flows past profiles with closed supersonic zones free of shocks. The procedure uses analytic continuation into a complex extension of the hodograph plane, where a stable finite difference scheme based on complex characteristics is used. Physically reasonable flows with a moderate adverse pressure gradient that can be presumed not to induce separation of the turbulent boundary layer are obtained with apparently much more rapidity and flexibility than is encountered with the other hodographs methods available, such as Nieuwland's [7]. A detailed A.E.C. report by Korn [5], including a print-out of his Fortran program, has been published for the case of symmetric airfoils without lift.

The A.E.C. cannot be expected to support a more extensive project to develop our airfoil computations into a tool available to engineers for everyday application. We have made feasibility studies that show we can now produce lifting shockless airfoils in less than one minute of C.D.C. 6600 computing time. However, before this was accomplished, it became necessary to make extensive parameter studies in order to achieve a closed profile, together with a moderate pressure distribution such that the boundary layer should not separate. In this proposal, we request that N.A.S.A. undertake to finance a continuation of our research so that our preliminary success can lead to a technique that any engineer unfamiliar with the mathematical subleties can have at his disposal as a workable and inexpensive computing program for transonic airfoil design. We intend to make the computer program available in such a form that it can be run on machines like the C.D.C. 6600 at Langley Research Center.
Proposal: Numerical Design of Transonic Shockless Airfoils

In addition to making lifting shockless transonic airfoil shapes easy to calculate, we propose to generalize our procedure so that a turbulent boundary layer correction can be made. Moreover, we want to prepare numerical schemes to calculate the flow past our shockless airfoils at off-design conditions so as to predict their aerodynamic characteristics mathematically.

All this will require the services of several senior scientists and computer programmers, in addition to the principal investigator.

Together with our program of mathematical research and development we would like to cooperate with N.A.S.A. in testing the performance of our lifting shockless airfoils in a wind tunnel. Because of the importance of suppressing boundary layer separation, if shock-free flow is truly to prevail, it becomes necessary to operate at such high Reynolds numbers that the boundary layer will become primarily turbulent. We hope, therefore, that tests on our airfoils can be conducted in a high speed wind tunnel.

In addition to the practical matter of systematizing and documenting our numerical scheme so that it can become a standard tool available to engineers for design purposes, we intend to investigate the physical properties and stability of smooth transonic flows. Early theoretical results [6] and [4] have shown that a smooth, steady transonic flow, if disturbed, will give rise to a shock. However, these shocks are weak and the disturbed flow with a weak shock could be described by appropriate singular solutions of the hodograph equations, but cannot be solved in quite the explicit manner described in Guderley [4], p. 122. However, in principle, this approach is feasible. In this direction, preliminary results have already been obtained concerning the correctness of the Dirichlet problem for Tricomi's mixed equation [6].

Principal Investigator: Paul R. Garabedian
Professor of Mathematics
References:

1. GARABEDIAN, PAUL R.


3. ......., and LIEBERSTEIN, H. M.

4. GUDERLEY, K. G.

5. KORN, D. G.

6. MORAWETZ, C. S.

7. NIEUWLAND, G. Y.

8. PEARCEY, H. H.

9. SPEE, B. M. and UIJLANHOET, R.
Curriculum Vitae

Paul R. Garabedian

Born: August 2, 1927, Cincinnati, Ohio

Education:
- AB 1948 Brown
- AM 1947 Harvard
- Ph. D. 1948 Harvard

Positions:
- National Research Council Fellow 1948-49
- Assistant Professor-Math, University of California 1949-50
- Assistant Professor-Math, Stanford, 1950-52
- Associate Professor-Math, Stanford, 1952-56
- Professor-Math, Stanford, 1956-59
- Professor-Math, Courant Institute of Mathematical Sciences, New York University, 1959 - present.

Honors:
- American Academy of Arts & Sciences
- Sloan Foundation Fellowship, 1961-63
- Guggenheim Fellowship, 1966.

Professional Societies

Memberships:
- American Math Society
- Society for Industrial and Applied Math
- National Research Council - Math Division

Recent Publications:


Recent Publications:


Curriculum Vitae

Cathleen Synge Morawetz

Born: May 5, 1923, Toronto, Canada

Education:

University of Toronto, 1940-43 Received B. A.
1944-45

Technical Assistant for Inspection Board
of the United Kingdom and Canada, 1943-44

Massachusetts Institute of Technology, 1945-46 Received M.S.

New York University: Research assistant and
student, 1946 - 50, Received Ph. D. in 1951.
Thesis in field of fluid dynamics on stability
of an implosion.

Positions:

Research Associate at M. I. T., 1951-52

New York University: Research Associate 1952-57
Assistant Professor 1957-60
Associate Professor 1960-65
Professor 1965 - present

Honors:

Guggenheim Fellow, 1966-67

Professional Societies:

American Math Society

Recent Publications:

......, Energy identities for the wave equation,

......, Exponential decay of solutions of the wave equation.

......, Transonic flow and mixed equations, Rendiconti del Seminario
Matematico dell Universita e del Politecnico di Torino, Vol. 25, pgs.


Curriculum Vitae

Frances Bauer

Born: July 5, 1923, New York City, N. Y.

Education:

A. B. Brooklyn College, 1943
Ph. D. in Applied Math, Brown Univ., 1948

Positions:

Research Associate, Brown Univ., 1945-48
Research Associate, Polytechnic Inst. of Brooklyn, 1949-50
Senior Mathematician, Reeves Instrument Corp., 1950-51, 1952-61
Mathematician, Bureau of Standards, contract with American University, 1951-52
Research Scientist, Courant Institute of Mathematical Sciences, 1961 - Present

Membership:

Sigma Xi, AMS, ACM

Honors:

Rockefeller Foundation Fellowship, 1943-45
Curriculum Vitae

David G. Korn

Born: August 28, 1943, Brooklyn, N. Y.

Education:

B.S. Mathematics - Rensselaer Polytechnic Institute, 1965

Ph. D. Mathematics - New York University, 1969

Positions:

Research Assistant, Courant Institute of Mathematical Sciences, 1965-69

Associate Research Scientist, Courant Institute of Mathematical Sciences, 1969 - Present

Honors:

Graduated Cum Laude

Nominated to Pi Mu Epsilon Math Honorary

National Science Foundation Fellowship

Professional Memberships:

SIAM
## Numerical Design of Transonic Shockless Airfoils

### Proposed Budget

**September 1, 1970 to August 31, 1971**

<table>
<thead>
<tr>
<th>SALARIES:</th>
<th>Requested of N.A.S.A.</th>
<th>N.Y.U. Contribution</th>
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<tbody>
<tr>
<td><strong>Professor Paul Garabedian</strong> [Principal Investigator]</td>
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</tr>
<tr>
<td>50% 9 months academic year</td>
<td>$ 7,625</td>
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<td><strong>Professor Cathleen S. Morawetz</strong></td>
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<td>16 2/3% 9 months academic year</td>
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<td><strong>David Korn</strong> Associate Research Scientist</td>
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<td><strong>1 Secretary</strong></td>
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<td>50% 12 months</td>
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<td><strong>Total Salaries</strong></td>
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</table>

| OVERHEAD [54% of Salaries] | $36,257 | $5,153 |
| FRINGE BENEFITS [13% of Salaries] | $8,728 | $1,240 |
| TRAVEL | $5,000 | |
| PUBLICATIONS | $2,500 | |
| COMPUTER TIME | $15,000 | |
| MISCELLANEOUS [Communications, Supplies, etc.] | $373 | |
| **Total Cost** | $135,000 | $15,935 |

*Note: Salaries are based on Estimated 1970-71 figures.*