REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE September 1999 -	3. REPORT TYPE AND DATES COVERED Final Report

4. TITLE AND SUBTITLE
Brockettfest: A Conference on Mathematical Control Theory

5. FUNDING NUMBERS
DAAG55-98-1-0391

6. AUTHOR(S)
John Baillieul

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Boston University
Boston, MA 02215

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U. S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
ARO 37868.1-MA-CF

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12 a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report summarizes a scientific meeting/conference which was supported in part by a grant from the Army Research Office. The conference was held in Cambridge, MA on October 23,24, 1998. The occasion marked the sixtieth birthday of Roger W. Brockett, and more than one hundred leading control theorists traveled to Boston to attend two days of lectures and a formal banquet. No formal conference record was published, but a volume of technical articles discussing current research related to Brockett's work was published. The book entitled *Mathematical Control Theory* is available from Springer-Verlag as indicated in the report.

14. SUBJECT TERMS

DTIC QUALITY INSPECTED 4

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION ON THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

DTIC QUALITY INSPECTED 4

19991102 150

BOSTON UNIVESITY

COLLEGE OF ENGINEERING

FINAL REPORT

Brockettfest:
A Conference on Mathmematical Control Theory

ARO Grant No. DAAG55-98-1-0391

Report prepared by

Professor John Baillieul
Department of Aerospace/Mechanical
Engineering
Boston University
617-353-9848
johnb@bu.edu

September, 1999

Abstract

This report summarizes a scientific meeting/conference which was supported in part by a grant from the Army Research Office. The conference was held in Cambridge, MA on October 23,24, 1998. The occasion marked the sixtieth birthday of Roger W. Brockett, and more than one hundred leading control theorists traveled to Boston to attend two days of lectures and a formal banquet. No formal conference record was published, but a volume of technical articles discussing current research related to Brockett's work was published. The book entitled *Mathematical Control Theory* is available from Springer-Verlag as indicated in the report.

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FINAL REPORT

Abstract

This report summarizes a scientific meeting/conference which was supported in part by a grant from the Army Research Office. The conference was held in Cambridge, MA on October 23,24, 1998. The occasion marked the sixtieth birthday of Roger W. Brockett, and more than one hundred leading control theorists traveled to Boston to attend two days of lectures and a formal banquet.

1 Perspectives in Control: A conference honoring the work of Roger W. Brockett

As quoted in the book The Experts Speak by C. Cerf and V. Navasky, James Ussher, Archbishop of Armagh in the seventeenth century, propounded that "The world was created on 22d October, 4004 B.C., at 6 o'clock in the evening." An event of note for our own professional community occurred on the same date nearly six millennia later when in 1938, our colleague Roger W. Brockett was born in Seville, Ohio. In honor of his 60-th birthday, a two-day symposium was held in Boston and Cambridge, Massachusetts, on October 23 and 24. The symposium received financial support of the U.S. Army Research Office and the National Science Foundation.

Among its many high points, the symposium started off with a keynote address by Karl Johan Åstrøm from the Lund Institute of Technology in Sweden, entitled "Automatic Control: A Perspective". The lecture was perfect for the occasion. Karl sketched the development of the field from the early days of the industrial revolution and the pre- and postwar era, via the stormy theoretical developments of the sixties, to today's high tech applications. He emphasized that control is in an essential way an enabling field, and he expressed this very aptly by stating that control is a field with a soul, but without a body. Particularly refreshing in this keynote address was the tone of contagious optimism concerning the great industrial relevance of the field of control combination with the computer technology.

The symposium featured about 40 speakers, the majority co-workers (mainly former Ph.D. students and post-docs) of Roger Brockett. It is no accident, of course, that the development of nonlinear control theory and Roger Brockett's career coincided, and all the speakers emphasized the inspiration which his work has provided for their own research. The talks ranged from nonlinear controllability and feedback linearization to quantum systems. Many speakers touched upon the various subtle aspects of the deceivingly simple looking non-linear system:

$$
\begin{aligned}
\dot{x}_1 &= u_1 \\
\dot{x}_2 &= u_2 \\
\dot{x}_3 &= x_1 u_2 - x_2 u_1,
\end{aligned}
$$

the Brockett integrator. That this would be a featured part of so many talks was foreseen by a number of enterprising graduate students who distributed t-shirts displaying these equations.

The symposium ended with a formal dinner. Formal is a relative notion. For the case at hand, it emphasized the elegant surroundings of the Harvard faculty club and the suggestion to honor the occasion by using fork and knife and not throw the food at the other guests. Sanjoy Mitter from MIT gave a light-hearted after-dinner *Laudatio* at the banquet.

A Festschrift was published for the occasion, Mathematical Control Theory, edited by John Baillieul and Jan C. Willems (Springer Verlag, 1998, ISBN 0-387-98317-1). It contains Roger Brockett's vitae, a list of his publications and his Ph.D. students and postdocs, and nine extensive articles about various aspects of the field to which Roger Brockett has made seminal contributions.

Brockettfest: Conference Photos, October 23,24, 1998

Karl Åstrøm and Louise Baxter and
Roger Brockett enjoy a light moment.

Carolann Brockett, Bill Levine, and Roberto
Canales discuss changes that have occurred
in the field over the past quarter century.
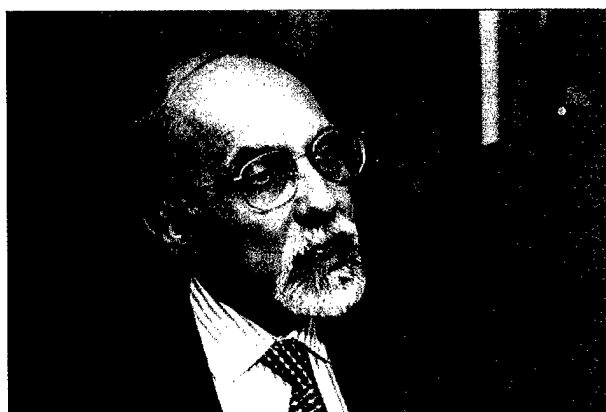
Sanjoy Mitter reflects on work he
has done with Brockett.

Karl Åstrøm gives an optimistic assessment
of the future.

Roger Brockett, Venkatesh ("Venky")
Narayanamurti and David Dobkin discuss
engineering principles in computer science

3   Conference Summary

The *Brockettfest* Conference was a great success, bringing together a large number of researchers for a focused two-day discussion of thirty year's research on modern mathematical control theory (and also very interesting applications in mechanics and computer science). The Conference was jointly sponsored and supported by the U.S. Army Research Office (Dr. Linda Bushnell), the National Science Foundation (Dr. Radhakisan S. Baheti), Harvard University, and Boston University. The meeting stretched over a two-day period—October 23,24, 1998 with technical sessions split between Boston University (Friday morning) and Harvard University. The banquet on Saturday, October 24, was yet an additional occasion for professional (as well as informal) interaction, and a number of speakers (both scheduled and *impromptu*) spoke about Brockett's work and its significance. The banquet was held in the very pleasant second floor suite of the Harvard Faculty Club. Summary statistics regarding the Conference are provided in the following table:

Brockettfest Summary Statistics	
Total attendance	130
Total number receiving partial support of travel	44
Total scheduled technical lectures	44
Sponsorship Agency funds were used to support participant expenses including round-trip airfare, meals, and lodging.	
Army Research Office	$30,000
Nat'l Science Found.	7,000

A summary of travel reimbursements to participants is given on the following page. *Additional participant support was provided through directly paid meal and meeting costs at the Conference, but these charges were not itemized on an individual participant basis.* The Conference speakers are listed together with their affiliations on the pages after that. The meeting had a strong international flavor with 19 of the speakers (slightly less than half) being from foreign institutions.

The Selection of the Program

The technical program was set by a small Program Committee consisting of John Baillieul (Boston University), Jan C. Willems (University of Groningen), Pierre Dupont (Boston University), and Sanjoy K. Mitter (MIT). All the plenary speakers were invited, but among the other speakers there was about an even split between invited and contributed talks. A sample letter of invitation is appended to this report.

Title	First Name	Last name	Amount Awarded		REMARKS	
Prof.	Karl	Astrom	$ 3,054.86		Keynote speaker	
Prof.	D.	Aeyels	$ 650.00			
Prof.	A.	Astolfi	$ 449.40			
Dr.	Walter	Baker	$ 300.00			
Prof.	John S.	Baras	$ 763.69			
Prof.	Anthony M.	Bloch	$ 725.31			
Prof.	Peter	Caines	$ 53.00			
DR.	Roberto	Canales	$ 624.00			
Prof.	Greg	Chirikjian	$ 410.77			
Dr.	Jim	Clark	$ 130.00			
Dr.	Martin	Clyde	$ 1,150.00			
Prof.	Peter E.	Crouch	$ 1,000.00			
Dr.	Jeroen	Dehaene	$ 561.20			
Prof.	David P.	Dobkin	$ 355.50			
Prof.	Leonid	Faybusovich	$ 500.00			
Prof.	P.A.	Fuhrmann	$ 2,100.00			
Prof.	Katsuhisa	Furuta	$ 934.67			
Prof.	Jacob	Hammer	$ 300.00			
Dr.	Bernard	Hanzon	$ 650.00			
Prof.	Uwe	Helmke	$ 650.00			
Prof.	Ron	Hirschorn	$ 500.00			
Prof.	Joseph	JaJa	$ 430.43			
Prof.	Hidenori	Kimura	$ 800.00			
Prof.	Arthur J.	Krener	$ 1,050.00			
Prof.	P.S.	Krishnaprasad	$ 800.00			
Dr.	Francoise	LAMNABHI-LAG	$ 509.10			
Prof.	Fatima Silva	Leite	$ 500.00			
Prof.	Naomi	Leonard	$ 285.00			
Prof.	Bill	Levine	$ 500.00			
Prof.	Josip	Loncaric	$ 520.83			
Prof.	Steve	Marcus	$ 300.00			
Prof.	Felipe	Monroy-Perez	$ 353.89			
Prof.	Bozenna	Pasik-Duncan	$ 395.47			
Prof.	Shanker	Sastry	$ 465.54			
Prof.	Eduardo D.	Sontag	$ 769.04			
Prof.	Hector J.	Sussmann	$ 787.94			
Prof.	Roberto	Tempo	$ 650.00			
Prof.	Duncan	Tyrone	$ 500.00			
Prof.	Darrell	Williamson	$ 1,000.00			
Prof.	Wing S.	Wong	$ 2,000.00			
Prof.	Yutaka	Yamamoto	$ 1,200.00			
Total			$ 29,679.64			

This provides a complete list of "Brockettfest" attendees who received reimbursement or partial reimbursement from Federal grant sources.

PERSPECTIVES IN CONTROL

A scientific conference in honor of

ROGER W. BROCKETT

Harvard University

on the occasion of his 60-th birthday

General Information

- The conference is open to anybody who wishes to attend. If you would like to attend the meeting, please preregister according to the instructions posted at http://eng.bu.edu/Brockettfest. Alternatively you may send e-mail to Brockettfest@math.rug.nl or JOHNB@enga.bu.edu. The information contained in your e-mail should include *(i)* your name, *(ii)* affiliation, and *(iii)* the number of banquet tickets you wish to order.

- The conference is held at Boston University and Harvard University. Registration will be held at the **Photonics Center** of **Boston University**, 8 St. Mary's Street, Boston (subway stop: Boston University Central, Green Line, Car B), starting at 8.00 a.m. on **Friday, October 23, 1998.**

- The registration fee is $ 100. This includes coffee, tea, and a copy of the book:

MATHEMATICAL CONTROL THEORY
Dedicated to Roger Brockett on his 60-th Birthday

J. Baillieul & J.C. Willems, Eds.
Springer-Verlag, NY
ISBN 0-387-98317-1

About the book:

This book contains a collection of scientific papers written for the occasion by former co-workers of Roger W. Brockett. It is a self-contained volume which surveys three decades of mathematical control theory and which at the same time describes how the work of Roger Brockett shaped and influenced the field. While intended as a commemorative volume, the book will also provide an important reference for graduate students and researchers working in control and system theory.

- The conference will be concluded with a dinner at the Harvard Faculty Club, at 7 p.m. on **Saturday, October 24, 1998**. Tickets for the dinner are $ 50 per person. Please mention special dietary requirements when ordering dinner tickets.

- Hotel accommodations for the meeting are described on the Web site `http://eng.bu.edu/Brockettfest`.

Program

Friday, October 23, 1998

The morning session of Friday, October 23, will take place in the Auditorium of the **Photonics Center** (Room 206) of **Boston University**, 8 St. Mary's Street, Boston (subway stop: Boston University Central, Green Line, Car B).

8.00 – 9.15	Arrival and registration of participants	
9.15 – 9.30	Opening	

Session 1:
Chairperson: J.C. Willems (University of Groningen)

9.30 – 10.30   Keynote address **Karl Johan Astrom**
Automatic Control - A Perspective

10.30 – 11.00   Coffee break

11.00 – 11.30   C.I. Byrnes (Washington University)
Geometry of Nevanlinna-Pick interpolation

11.30 – 12.00   P.A. Fuhrmann (Ben Gurion University)
Realization theory, the Riccati equation and spectral factorization

12.00 – 12.30   A.J. Krener (University of California)
Feedback linearization

12.30 – 13.00   C.F. Martin (Texas Tech)
Obstructions to simultaneous stabilization

13.00 – 15.00   Lunch

The afternoon sessions of Friday, October 23, will take place in the **Science Center of Harvard University** (subway stop: Harvard Square, Red Line). It takes about 30 minutes to transfer from BU to Harvard by subway.

Session 2: Lecture Hall A
Chairperson: (P.S. Krishnaprasad, University of Maryland)

15.00 – 15.25   K. Furuta (Tokyo Institute of Technology)
                 Generation of chaos using discontinuous sliding planes
15.25 – 15.50   U. Helmke (University of Würzburg)
                 Scaling actions and the control of numerical algorithms
15.50 – 16.15   F. Silva Leite (University of Coimbra)
                 Spline interpolation on Lie groups and spheres
16.15 – 16.40   D. Liberzon (Yale University)
                 Stability of switched systems: a Lie-algebraic condition

16.40 – 17.00   Tea break

17.00 – 17.25   F. Monroy-Perez (Universidad Autonoma-Metro-politana)
                 Optimal control problem on the Heisenberg group
17.25 – 17.50   S.T. Smith (Lincoln Labs)
                 The geometry of orthogonally constrained algorithms
17.50 – 18.15   V. Sundarapandian (Washington University)
                 A necessary condition for local asymptotic stability of equilibria
18.15 – 18.40   D. Williamson (Australian National University)
                 Tensegrity systems: topology, analysis and control

Session 3: Lecture Hall D
Chairperson: (J.S. Baras, University of Maryland))

15.00 – 15.25   D.J. Bell (UMIST)
                 Junction points in singular optimal control
15.25 – 15.50   J.J. Clark (McGill University)
                 Control of active vision systems
15.50 – 16.15   D.P. Dobkin (Princeton University)
                 A novel representation for geometric objects with applications
16.15 – 16.40   L. Faybusovich (University of Notre Dame)
                 Jordan algebras, symmetric cones and interior-point methods

16.40 – 17.00   Tea break

17.00 – 17.25   J. Hammer (University of Florida)
                  Approximate model matching in nonlinear control
17.25 – 17.40   B. Hanzon (Free University Amsterdam)
                  Model reduction in H_2 using matrix solutions of polynomial equations
17.40 – 18.15   J.F. JaJa (University of Maryland)
                  On the design of practical parallel algorithm for combinatorial computing and image processing
18.15 – 18.40   P. Caines (McGill University)
                  On the controllability of Hamiltonian and other nonlinear systems

Saturday October 24, 1998

The sessions of Saturday, October 24, will take place in the **Science Center of Harvard University**

Session 4: Lecture Hall A
Chairperson: J. Baillieul (Boston University)

 8.30 –   9.00   J.S. Baras (University of Maryland)
                  Group invariance and symmetries in control systems and mathematical physics
 9.00 –   9.30   A.M. Bloch (University of Michigan)
                  Double bracket equations in optimization, control. and mechanics
 9.30 – 10.00   P.S. Krishnaprasad (University of Maryland)
                  Patterns in control

10.00 – 10.30   Coffee break

10.30 – 11.00   J.E. Marsden (Caltech)
                  Stabilization of balance systems
11.00 – 11.30   E.D. Sontag (Rutgers University)
                  Stabilization under observation errors
11.30 – 12.00   H.J. Sussmann (Rutgers University)
                  Geometry and optimal control

12.30 – 13.30   Lunch

Session 5: Lecture Hall A
Chairperson: C.I. Byrnes (Washington University)

13.30 – 13.55   B.R. Barmish (University of Wisconsin)
                  Probabilistic design for quadratic stabilizability as a convex program
13.55 – 14.20   G.S. Chirikjian (Johns Hopkins University)
                  Closed-form solutions of the heat equation on SO(3): applications of rotational diffusion and averaging
14.20 – 14.55   T.E. Duncan (University of Kansas)
                  Fractional Brownian motion
14.55 – 15.20   T. Taylor (Arizona State University)
                  Stochastic matrices: geometry, control and asymptotics

15.20 – 15.35   Tea break

15.35 – 16.00   R. Tempo (Politecnico di Torino)
                  Probabilistic robustness analysis of uncertain control systems
16.00 – 16.25   A.S. Willsky (MIT)
                  Why the world can't do without more estimation theory
16.25 – 16.50   W.S. Wong (Chinese University of Hong Kong)
                  Estimation and control problems with finite communication bandwidth constraints
16.50 – 17.15   Y. Yamamoto (Kyoto University)
                  Sampled-data systems: the past and the future
17.15 – 17.40   V.A. Yatsenko (National Space Agency of Ukraine)
                  Parameter estimation of almost periodic signal via controllable bilinear observations

Session 6: Lecture Hall D
Chairperson: (P.E. Crouch, Arizona State University)

13.30 – 13.55 A. Astolfi (Imperial College)
Control of the Brockett integrator: an ever challenging problem

13.55 – 14.20 R. Hirschorn (Queen's University)
Control of nonlinear systems with friction

14.20 – 14.55 H. Kimura (Tokyo University)
Uniqueness of Representation of Model Set

14.55 – 15.20 S. Lloyd (MIT)
Nonholonomic feedback control of quantum systems

15.20 – 15.35 Tea break

15.35 – 16.00 J. Loncaric (NASA LaRC)
Sensor/actuator placement via optimal distributed feedback

16.00 – 16.25 S. Nikitin (Arizona State University)
Nonlinear control synthesis and Brockett's view of isoperimetric problems

16.25 – 16.50 V. Polotski (Ecole Polytechnique)
Time-varying state feedback and output injection

16.50 – 17.15 D. Seto (Carnegie Mellon University)
On dynamic reconfiguration of real-time control systems

19.00 Dinner at the Harvard Faculty Club
Prof. S.K. Mitter (MIT) will give an after-dinner Laudatio.

List of registered participants (October 15, 1998):

D. Aeyels (University of Gent)
S.K. Agrawal (University of Delaware)
A. Astolfi (Imperial College)
K.J. Astrom (Lund Institute of Technology)
D. Atroune (University of Georgia)
R. Baheti (National Science Foundation)
J. Baillieul (Boston University)
W. Baker (McKinsey & Company)
J.D. Baras (University of Maryland)
B.R. Barmish (University of Wisconsin)
D.J. Bell (UMIST)
A.M. Bloch (University of Michigan)
E. Bristol (The Foxboro Co.)

L. Bushnell (Army Research Office)
C.I. Byrnes (Washington University)
R.Canales (IIE, Mexico)
J. Chandra (US Army Research Laboratory)
G.S. Chirikjian (Johns Hopkins University)
M. Chyba (Harvard University)
J.J. Clark (McGill University)
D. Cochran (Arizona State University)
S. Coraluppi (Alphatech)
P.E. Crouch (Arizona State University)
L. Dai (Washington University)
J. Dehaene (University of Leuven)
D.P. Dobkin (Princeton University)
T.E. Duncan (University of Kansas)
L. Faybusovich (University of Notre Dame)
N.J. Ferrier (University of Wisconsin)
M. Fu (University of Maryland)
P.A. Fuhrmann (Ben Gurion University)
K. Furuta (Tokyo Institute of Technology)
J. Hammer (University of Florida)
B. Hanzon (Free University Amsterdam)
U. Helmke (University of Würzburg)
R. Hirschorn (Queen's University)
Y.-C. Ho (Harvard University)
D. Hristu (Harvard University)
J.F. JaJa (University of Maryland)
T. Kailath (Stanford University)
N. Kajena (Harvard University)
K. Keeler
H. Kimura (University of Tokyo)
J. Kosowsky (Harvard University)
G. Kovatch (U.S. Department of Transportation)
O.P. Kreidl (Alphatech)
A.J. Krener (University of California)
M. Krichman (Rutgers University)
P.S. Krishnaprasad (University of Maryland)
F. Lamnabhi-Lagarrigue (Laboratoire des Signaux et Systèmes, Supelec)
F. Silva Leite (University of Coimbra)
N.E. Leonard (Princeton University)
W.S. Levine (University of Maryland)
D. Liberzon (Yale University)
S. Lloyd (MIT)

J. Loncaric (NASA LaRC)
S. Marcus (University of Maryland)
J.E. Marsden (Caltech)
C.F. Martin (Texas Tech)
S.K. Mitter (MIT)
F. Monroy-Perez (Universidad Autonoma-Metropolitana)
D. Montana (BBN)
K. Morgansen (Harvard University)
A.S. Morse (Yale University)
N. Munro (UMIST)
R.M. Murray (United Technologies)
S. Nikitin (Arizona State University)
B. Pasik-Duncan (University of Kansas)
V. Polotski (Ecole Polytechnique)
M. Pukmel
M. Rabi (Harvard University)
N. Rao (SCT Corp.)
S. Sastry (University of California)
D. Seto (Carnegie Mellon University)
M.A. Shayman (University of Maryland)
S.T. Smith (Lincoln Labs)
E.D. Sontag (Rutgers University)
P.P. Sotiriadis (Harvard University)
V. Sundarapandian (Washington University)
H.J. Sussmann (Rutgers University)
A. Tannenbaum (University of Minnesota)
T. Taylor (Arizona State University)
R. Tempo (Politecnico di Torino)
J. Tsitsiklis (MIT)
N. Twum-Danso
Y. Wang (Florida Atlantic University)
J.C. Willems (University of Groningen)
D. Williamson (Australian National University Canberra)
A.S. Willsky (MIT)
W.S. Wong (Chinese University of Hong Kong)
Y. Yamamoto (Kyoto University)
V.A. Yatsenko (National Space Agency of Ukraine)

Appendix:
Letter of Invitation

August 14, 1998

Professor P.E. Crouch
Dean College of Engineering and Applied Sciences
P.O. Box 875506
Arizona State University
Tempe, AZ 85287-5506

Dear Peter,

It is a pleasure to share some good news regarding the forthcoming October Conference we are holding in honor of Roger W. Brockett's 60 birthday. With recently awarded financial support form the Army Research Office, the organizers have sufficient funds to cover reasonable costs associated with your travel. I am thus able to offer you up to $1,000.00 in travel expense reimbursement. Because of U.S. Government restrictions on the use of these funds, you will be required to use a U.S. flag carrier for any international travel. The detailed terms and conditions of our grant include the following:

> Travel supported by U.S. government funds under this grant shall use U.S. flag air carriers for international air transportation of people and property to the extent that such service is available in accordance with the International Air Transportation Fair Competitive Practices Act of 1974 and the interpretative guidelines issued by the Comptroller General of the United States in the March 31, 1981 amendment to Comptroller General Decision B138942.

It is also important to note that the funds we provide will be given as reimbursements, and thus hotel and meal receipts as well as airline ticket stubs will be required.

Let me take this opportunity to remind you that it is a good idea to make your hotel reservations at this time if you have not already done so. (The block of hotel rooms will only be held until the middle of September, and rooms in the Boston area are very difficult to find during the month of October.) Hotel information is available on our Web site: http://eng.bu.edu/Brockettfest.

Jan and I are very much looking forward to seeing you at this festive occasion honoring the life's work (to date) of Roger W. Brockett.

Sincerely,

John Baillieul
(on behalf of Jan Willems)

PS: The program for 'Brockettfest' will be available soon on our Web site http://eng/bu.edu.Brockettfest. Please note that the Friday morning kickoff sessions will take place at Boston University, Room 206, Photonics Center, 8 St. Mary's Street. All other sessions, including those of Friday afternoon, will take place in the Science Center at Harvard University.