

## OSCILLATORY BEHAVIOR OF SECOND ORDER NONLINEAR DELAY DIFFERENTIAL EQUATIONS WITH POSITIVE AND NEGATIVE NEUTRAL TERMS

SAID R. GRACE, JOHN R. GRAEF AND IRENA JADLOVSKÁ

*Abstract.* The aim of the paper is to initiate a study of the oscillation of solutions of second order nonlinear differential equations with positive and negative nonlinear neutral terms. The results are illustrated by some examples.

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### REFERENCES

- [1] R. P. AGARWAL, M. BOHNER, T. LI, AND C. ZHANG, *Oscillation of second-order differential equations with a sublinear neutral term*, Carpathian Journal of Mathematics **30** (2014), 1–6.
- [2] M. BOHNER, S. R. GRACE, AND I. JADLOVSKÁ, *Oscillation criteria for second-order neutral delay differential equations*, Electron. J. Qual. Theory Differ. Equ. **2017** (2017), No. 60, 1–12.
- [3] T. CANDAN AND R. S. DAHIYA, *Oscillation of mixed neutral differential equations with forcing term*, in: “Dynamical Systems and Differential Equations (Wilmington, NC, 2002)”, Discrete Contin. Dyn. Syst. 2003, suppl., 167–172.
- [4] P. DAS, *Oscillations of mixed neutral equations caused by several deviating arguments*, Bull. Calcutta Math. Soc. **86** (1994), 135–146.
- [5] S. R. GRACE, *Oscillatory behavior of second-order nonlinear differential equations with a nonpositive neutral term*, Mediterr. J. Math. **14** (2017), Art. 229, 12pp.
- [6] S. R. GRACE AND J. R. GRAEF, *Oscillatory behavior of second order nonlinear differential equations with a sublinear neutral term*, Mathematical Modelling and Analysis, **30** (2018), 217–226.
- [7] J. K. HALE, *Functional Differential Equations*, Applied Mathematical Sciences, Vol. 3, Springer-Verlag, New York, 1971.
- [8] G. H. HARDY, I. E. LITTLEWOOD, AND G. POLYA, *Inequalities*, Cambridge University Press, Cambridge, Mass, USA, 1959.
- [9] R. G. KOPLATADZE AND T. A. CHANTURIYA, *Oscillating and monotone solutions of first-order differential equations with deviating argument (in Russian)*, Differ. Uravn. **18** (1982), 1463–1465.
- [10] G. LADAS AND I. P. STAVROULAKIS, *Oscillation caused by several retarded and advanced arguments*, J. Differ. Equations, **44** (1982), 134–152.
- [11] H. LI, Z. HAN, AND Y. SUN, *Existence of non-oscillatory solutions for second-order mixed neutral differential equations with positive and negative terms*, Int. J. Dyn. Syst. Differ. Equ. **7** (2017), 259–271.
- [12] T. LI AND Y. V. ROGOVCHENKO, *Oscillation of second-order neutral differential equations*, Math. Nachr. **288** (2015), 1150–1162.
- [13] T. LI AND Y. V. ROGOVCHENKO, *Oscillation criteria for even-order neutral differential equations*, Appl. Math. Lett. **61** (2016), 35–41.
- [14] T. LI, Y. V. ROGOVCHENKO, AND C. ZHANG, *Oscillation of second-order neutral differential equations*, Funkcial. Ekvac. **56** (2013), 111–120.
- [15] CH. G. PHILOS, *On the existence of nonoscillatory solutions tending to zero at  $\infty$  for differential equations with positive delays*, Arch. Math. (Basel) **36** (1981), 168–178.
- [16] Y. QI AND J. YU, *Oscillation of second order nonlinear mixed neutral differential equations with distributed deviating arguments*, Bull. Malays. Math. Sci. Soc. **38** (2015), 543–560.

- [17] S. SELVARANGAM, B. RANI, AND E. THANDAPANI, *Some new oscillation theorems for second-order Euler-type differential equations with mixed neutral terms*, Adv. Pure Appl. Math. **8** (2017), 163–173.
- [18] H. SHI AND B. YUZHEN, *Oscillatory behavior of a second order nonlinear advanced differential equation with mixed neutral terms*, Adv. Difference Equ. **2019** (2019), No. 468, 18 pp.
- [19] S. TAMILVANAN, E. THANDAPANI, AND J. DŽURINA, *Oscillation of second order nonlinear differential equations with sub-linear neutral term*, Differ. Equ. Appl. **9** (2017), 29–35.
- [20] E. TUNÇ AND O. ÖZDEMİR, *On the oscillation of second-order half-linear functional differential equations with mixed neutral term*, J. Taibah Univ. Science **13** (2019), 481–489.
- [21] R. XU AND F. MENG, *Some new oscillation criteria for second order quasi-linear neutral delay differential equations*, Appl. Math. Comput. **182** (2006), 797–803.